

ESTCP Cost and Performance Report

(EW-201350)



Portsmouth Naval Shipyard Microgrid and Ancillary Services – Kittery, ME

August 2017

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COST & PERFORMANCE REPORT

Project: EW-201350

TABLE OF CONTENTS

	Page
EXECUTIVE SUMMARY	ES-1
1.0 INTRODUCTION	1
1.1 BACKGROUND	1
1.2 OBJECTIVE OF THE DEMONSTRATION.....	2
1.3 REGULATORY DRIVERS	2
2.0 TECHNOLOGY DESCRIPTION	3
2.1 TECHNOLOGY OVERVIEW.....	3
2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY	9
3.0 PERFORMANCE OBJECTIVES	13
4.0 FACILITY/SITE DESCRIPTION.....	17
4.1 FACILITY/SITE LOCATION AND OPERATIONS	17
4.2 FACILITY/SITE CONDITIONS	18
5.0 TEST DESIGN	21
5.1 CONCEPTUAL TEST DESIGN.....	21
5.2 BASELINE CHARACTERIZATION	23
5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS	24
5.4 OPERATIONAL TESTING.....	31
5.5 DATA COLLECTION	32
5.6 DATA RESULTS.....	33
6.0 PERFORMANCE ASSESSMENT	35
7.0 COST ASSESSMENT.....	37
7.1 COST MODEL	37
7.2 COST DRIVERS	38
7.3 COST ANALYSIS AND COMPARISON	39
8.0 IMPLEMENTATION ISSUES	49
APPENDIX A POINTS OF CONTACT	A-1

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LIST OF FIGURES

	Page
Figure 2-1. MCS System Architecture	4
Figure 2-2. BESS Major Components	8
Figure 2-3. Volt-Ampere Reactive (VAR) Support Diagram	9
Figure 2-4. Energy Storage Technology Range of Application	10
Figure 3-1. Deregulated Electricity Markets	16
Figure 4-1. PNS Demonstration Area.....	17
Figure 4-2. Demonstration Site.....	18
Figure 5-1. System Architecture Diagram.....	28
Figure 5-2. BESS Installation through Demonstration Schedule	31
Figure 5-3. Main MCS/FLS HMI Screen	32
Figure 7-1. 20-Year Economics of the 500 kW/580 kWh Saft IM20+ BESS Participating in ISO-NE Regulation.....	44
Figure 7-2. Expected 20-Year Economics of a 500 kW/500 kWh BESS with 2017 Equipment Pricing Participating in ISO-NE Regulation.....	45

LIST OF TABLES

	Page
Table 2-1. Operational Steps to Island	6
Table 3-1. Performance Objectives, Phase I – MCS/FLS	13
Table 3-2. Performance Objectives, Phase II – BESS	15
Table 5-1. MCS/FLS Commissioning and PVT Schedule.....	31
Table 7-1. Cost Model for MCS/FLS.....	37
Table 7-2. Cost Model for BESS.....	38
Table 7-3. Annual Supplement to NIST Handbook 135 (2013) Table A-1 Showing SPV Factors for Finding the Present Value of Future Single Costs (Non-Fuel)	40
Table 7-4. Annual Supplement to NIST Handbook 135 (2013) Table A-2 Showing UPV Factors for Finding the Present Value of Annually Recurring Uniform Costs (Non-Fuel) .	41

ACRONYMS AND ABBREVIATIONS

AAC	Annual Avoided Cost
AGC	Automatic Generator Control
ATTR	Alternative Technology Regulation Resource
BESS	Battery Energy Storage System
CAISO	California Independent System Operator
CGT	Combustion Gas Turbine
CMP	Central Maine Power
DCS	Digital Control System
DNP3	Distributed Network Protocol
DoD	U.S. Department of Defense
ECM	Energy Conservation Measure
ERCOT	Electric Reliability Council of Texas
ESPC	Energy Savings Performance Contract
ESTCP	Environmental Security Technology Certification Program
FERC	Federal Energy Regulatory Commission
FLS	Fast Load Shed
GB	Gigabyte(s)
GE	General Electric
GOOSE	Generic Object Oriented Substation Events
GPS	Global Positioning System
GTG	Gas Turbine Generator
HDD	Hard Disk Drive
HMI	Human Machine Interface
hr	Hour(s)
HRSG	Heat Recovery Steam Generator
HVAC	Heating, Ventilation, and Air Conditioning
IA	Interconnection Agreement
IEC	International Electrotechnical Commission
IED	Intelligent Energy Device
IEEE	Institute of Electrical and Electronics Engineers
I/O	Input/Output
ISO	Independent System Operator
ISO-NE	Independent System Operator for New England
kV	Kilovolt(s)
kW	Kilowatt(s)

kWh	kilowatt hour(s)
LAN	Local Area Network
lb/hr	Pound(s) Per Hour
LCC	Life-Cycle Cost
LCD	Liquid-Crystal Display
Li-ion	Lithium-Ion
LOC	Lost Opportunity Cost
LoU	Loss of Utility
MCS	Microgrid Control System
MISO	Midwest Independent System Operator
MPLS	Multiprotocol Label Switching
MW	Megawatt(s)
MW/min	Megawatt(s) per Minute
ms	Millisecond(s)
NAVFAC	Naval Facilities Engineering Command
NIST	National Institute of Standards and Technology
NTP	Network Time Protocol
NY-ISO	New York Independent System Operator
PCS	Power Conversion System
PI	Principal Investigator
PJM	PJM Interconnection LLC
PNS	Portsmouth Naval Shipyard
PTP	Precision Time Protocol
PVT	Performance Verification Test
PWD	Public Works Department
RCP	Regulation Clearing Price
RTO	Regional Transmission Organization
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SCP	Site Commissioning Plan
SMART RSTP	Rapid Spanning Tree Protocol
SOC	State of Charge
TB	Terabyte(s)
UPV	Uniform Present Value

EXECUTIVE SUMMARY

OBJECTIVE

The technical objective of this project is to demonstrate that the emerging technologies of Fast Load Shed (FLS)-capable microgrid controls and Battery Energy Storage Systems (BESSs) can be integrated with onsite generation at military bases to enhance the security and reliability of electric service to the base, provide valuable ancillary services to the electric grid Independent System Operator (ISO), and generate cost savings for the Government.

TECHNOLOGY DESCRIPTION

This project uniquely integrates several innovative technologies to provide cost-effective solutions for military energy security. These technologies include a 500-kilowatt (kW)/580-kilowatt-hour (kWh) BESS to provide on-demand power capacity during transitions from grid power to island power and to provide ongoing voltage and frequency control to the ISO. A new FLS system will integrate the BESS and a variety of existing onsite generation assets to implement a prioritizable shedding scheme and interface the facility's power system into the Independent System Operator for New England (ISO-NE) ancillary service power markets. The control system includes new metering so the FLS can intelligently select the loads to shed in order to balance with available supply. Combination of the FLS and BESS will considerably enhance the value of the Navy's existing onsite generation assets. Currently:

- Existing generation assets include two 5.0 megawatt (MW) combustion turbines and two 1.5 MW emergency diesel generators. Yet, this 13 MW total of onsite generation capacity could not prevent a Shipyard-wide blackout when grid power is unexpectedly lost, because fast load shedding control did previously exist.
- Batteries can provide ancillary services to the ISO but are very expensive to install and operate. By combining a BESS with the onsite generation assets at the Shipyard, it is expected that frequency regulation can be provided at a lower cost per capacity when compared to systems solely dedicated to providing ancillary services.

DEMONSTRATION RESULTS

It is expected that the results of this project will show that an investment in these technologies would significantly enhance the energy security of the Shipyard by maintaining power to all critical loads in the event of a loss of grid supply, avoiding otherwise lost production time and costs. The potential for reduction in net energy costs due to revenues from the provision of ancillary services to the ISO-NE grid is also demonstrated. The potential for broad implementation of this system across U.S. Government installations is promising.

IMPLEMENTATION ISSUES

Retrofitting new FLS-capable protective relaying into an existing electrical distribution system offers substantial challenges, specifically in obtaining accurate electrical drawings of existing equipment, which in some cases may be more than 30 years old, and understanding the flow of power when islanding. Also, implementation of grid-scale energy storage posed a challenge with lack of standardization between manufacturers, equipment reliability, and corporate stability, as can be expected when working with any nascent technology.

1.0 INTRODUCTION

The objective of this project is to demonstrate that the emerging technologies of Microgrid Control Systems (MCS) and Battery Energy Storage Systems (BESSs) can be integrated with onsite generation at military bases to enhance the security and reliability of electric service to the base, provide valuable ancillary services to the electric grid Independent System Operator (ISO), and generate cost savings for the Government.

This project uniquely integrates several innovative technologies to provide cost-effective solutions for military energy surety. These technologies include a 500-kilowatt (kW)/580-kilowatt-hour (kWh) BESS to assure power quality on-base at Portsmouth Naval Shipyard (PNS) during transitions from grid power to island power, and to provide ongoing frequency regulation to the New England electrical grid. In addition, a new MCS will integrate the BESS and a variety of existing onsite generation assets to implement a Fast Load Shed (FLS) scheme. The control system includes new metering so the MCS can intelligently select the loads to shed in order to balance with available onsite generation supply.

By deploying existing generation assets (which most military bases already have) in new ways through the systems proposed here, the Government can generate revenues (from the sale of ancillary services to the ISO) that could not be previously exploited without the BESS. The proposed system provides a more cost-effective way to capture revenues when compared to other energy storage installations where the core function may be to solely provide an ancillary service.

This investment will significantly enhance the energy security of the Shipyard by maintaining power to all critical loads in the event of a loss of grid supply, avoiding otherwise lost production time and costs. Net energy costs would also be reduced due to revenues from the provision of ancillary services to the Independent System Operator for New England (ISO-NE) grid. If successful, the potential for broad implementation of this system across U.S. Government installations is promising.

The demonstration will be split into two phases:

Phase I – MCS/FLS will integrate General Electric's (GE's) MCS with FLS to demonstrate islanding and energy surety for the Shipyard. The MCS will exercise control of the BESS during "Microgrid" operation.

Phase II – BESS is participation in ISO-NE's regulation market.

1.1 BACKGROUND

The U.S. Department of Defense (DoD) community recognizes that the aging infrastructure of the commercial power grid results in frequent power outages. Portsmouth Naval Shipyard experiences two to three such outages each year. These outages have resulted in the tripping of the Shipyard generating plants with the resultant disruptions in Shipyard Operations. The successful demonstration of FLS at PNS represents existing technology that can be deployed at any DoD facility where there is onsite generation with or without renewable energy. If these energy supplies are not sufficient to support the full load of the facility, then FLS will allow the most critical resources to stay online and support the mission critical loads and the maximum amount of non-critical loads.

1.2 OBJECTIVE OF THE DEMONSTRATION

The technical objective of this project was to demonstrate that the emerging technologies of MCS and BESS can be integrated with the local grid electric supplier both to increase energy surety of onsite generation and to provide economic value to the ISO. The economic value to the utility provides a revenue stream that can help pay for the upfront costs. This demonstration project shows how the Government can pay for energy surety upgrades with private capital instead of, or in combination with, appropriated Government funds. This should dramatically accelerate the pace of implementation of this essential electrical infrastructure upgrade at mission-critical military facilities.

1.3 REGULATORY DRIVERS

Federal Energy Regulatory Commission (FERC) Order 755¹

FERC Order 755 is significant to energy storage participating in regulation markets such as ISO-NE, New York Independent System Operator (NY-ISO), PJM Interconnection LLC (PJM), Electric Reliability Council of Texas (ERCOT), and California Independent System Operator (CAISO) offering higher revenue potential. New rules require the recognition of speed and accuracy—two attributes of energy storage systems such as the BESS in this demonstration—and provide additional value in the form of higher payments to these assets. To date, ISO-NE and PJM are the only markets to come into compliance with the new rules, with CAISO, ERCOT, and Midwest Independent System Operator (MISO) in development.

FERC 18 Code of Federal Regulations (CFR) Part 35²

The FERC is proposing to amend its regulations under the Federal Power Act (FPA) to remove barriers to the participation of electric storage resources and distributed energy resource aggregations in the capacity, energy, and ancillary service markets operated by regional transmission organizations (RTOs) and ISOs. Specifically, the regulation proposes to require each RTO and ISO to revise its tariff to (1) establish a participation model consisting of market rules that, recognizing the physical and operational characteristics of electric storage resources, accommodates their participation in the organized wholesale electric markets and (2) define distributed energy resource aggregators as a type of market participant that can participate in the organized wholesale electric markets under the participation model that best accommodates the physical and operational characteristics of its distributed energy resource aggregation.

DoD Directive 4180.01³

This Directive substantiates the DoD's policy to enhance military capability, improve energy security, and mitigate costs in its use and management of energy.

¹ <https://www.ferc.gov/whats-new/comm-meet/2011/102011/E-28.pdf>.

² <https://www.gpo.gov/fdsys/granule/CFR-2011-title18-vol1/CFR-2011-title18-vol1-part35>.

³ http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/418001_2014.pdf.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

Ameresco installed and integrated the following new systems at PNS:

- 500 kW/580 kWh BESS to assure power quality on-base during transitions from grid power to island power, and to provide frequency regulation to the New England electric grid. The system includes a containerized battery, inverter, Site Controller, and communications hardware required to communicate with ISO-NE.
- MCS to implement an FLS solution.
- The MCS includes new metering in feeder controllers (19 breakers at the Power Plant, 13 breakers at Substation 3, and the 2 Utility tie breakers [F1 and F12] at Franklin Substation). This metering data is used by the MCS to adaptively calculate the steady-state generation-load balance for changing power system conditions and select the prioritized loads to shed in order to maintain this balance following the detection of the Loss of Utility (LoU). This action will prevent the operating turbine generators from tripping on an overload. The feeder controllers provide relay trip control of 29 existing breakers (13 at the Power Plant, 13 at Substation 3, and 3 at Franklin Substation).
- Dedicated fiber-optic communication system to allow monitoring of key components (e.g., switches, status of battery banks) at the central controller.
- Global Positioning System (GPS) time synchronization of the MCS components.

Phase I – MCS/FLS

During Phase I, a GE C90^{Plus} and F35s were implemented to provide fast load shedding for an LoU event (PNS islanded) and BESS control during Microgrid Dispatch. The C90^{Plus} and F35 devices are at commercial stage and have been used in similar systems at industrial facilities, and provide the flexibility and programmability to implement the key objectives of this demonstration. A high-level system architecture for the MCS is shown in Figure 2-1. Please see Appendix E of the Final Report for the full-size document.

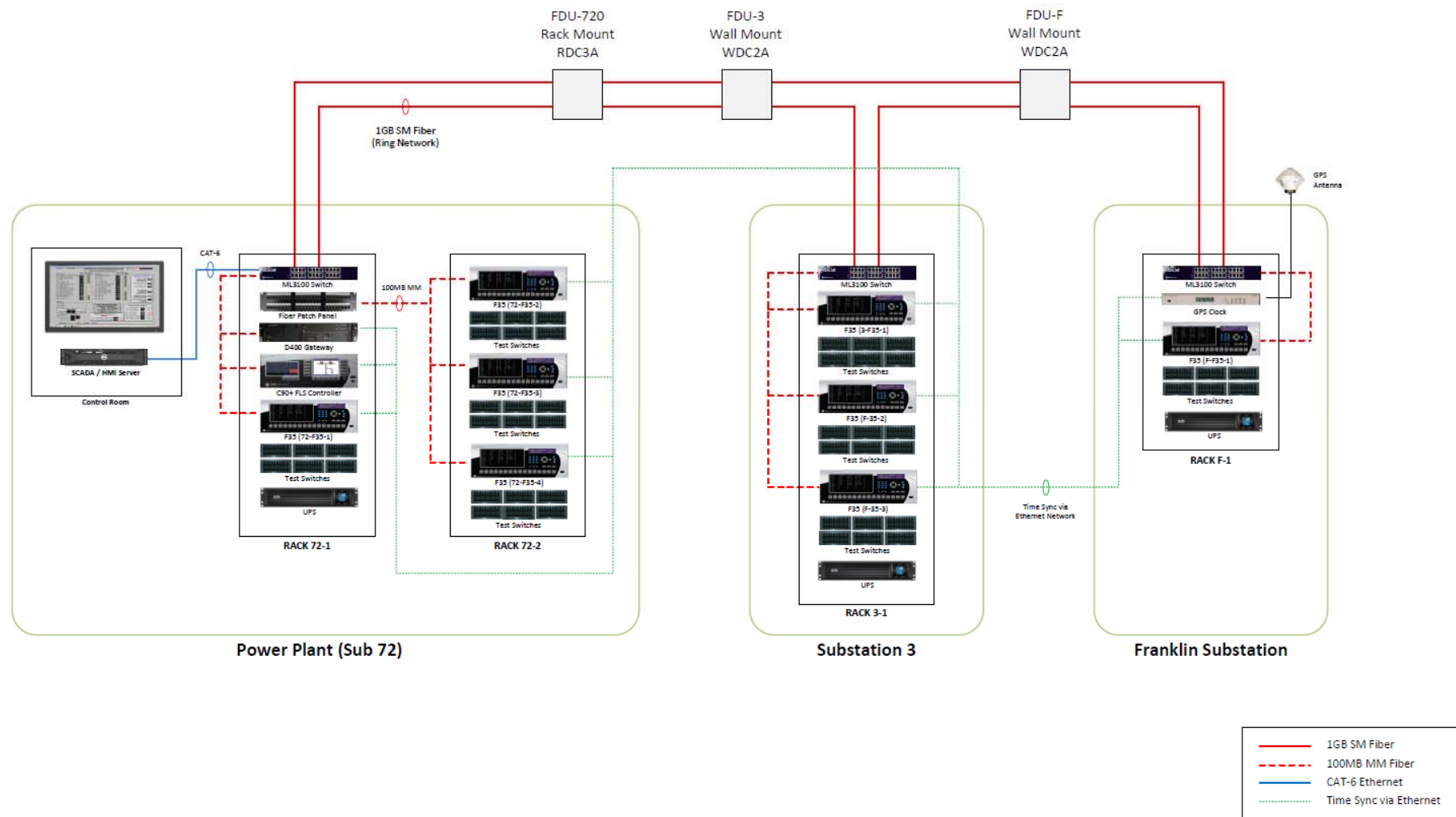


Figure 2-1. MCS System Architecture

Major Components

Main Substation Controller Subsystem – The main substation controller subsystem is the master control required to coordinate fast load shedding, dispatch of BESS during islanding, and historical data archiving of events. The Main Substation Controller Subsystem consists of a D400 substation gateway for the communication interface with the BESS Site Controller for data acquisition for all conditions. The D400 also controls Microgrid Dispatch of the BESS following LoU and monitors the BESS performance under Microgrid Dispatch. The FLS control is performed by the GE Multilin™ C90^{Plus} FLS controller. A local Microsoft Windows-based server provides configuration services for the system's devices. The server is equipped with GE's CIMPLICITY Supervisory Control and Data Acquisition (SCADA) software to provide the Operator with visual displays of system conditions, alarms, and control as well as data acquisition and storage.

Feeder Controllers – Three feeder control cabinets are provided to interface the Main Substation Controllers to the 13.2 kilovolt (kV) circuit breakers located in the Power Plant, Substation 3, and Franklin Substation. The feeder controller is based on the GE Multilin F35 feeder protection system and these units are responsible for:

Ethernet Communications – A 1-gigabit per second fiber optic Ethernet ring communications network has been installed with a GE ML3000-managed Ethernet switch located at each site (Power Plant, Substation 3, and Franklin Substation). The ring design provides high reliability and a secure communications architecture. The ML3000 switches are equipped with a SMART Rapid Spanning Tree Protocol (RSTP) feature that allows for recovery from faults in ring network architectures in <5 milliseconds (ms) per switch in the network—10 times faster than generally available in standard Ethernet switches. The switch provides for 10/100 Megabits per second communications to each connected device.

The FLS scheme employs International Electrotechnical Commission (IEC) 61850 Generic Object Oriented Substation Events (GOOSE) messaging to provide high-speed communications between the GE C90^{Plus} and the F35 feeder controllers. Modbus Transmission Control Protocol (TCP)/Internet Protocol (IP) is used to access data from the GE devices and the Dynapower Power Conversion System (PCS) by the D400 and the Human Machine Interface (HMI)/SCADA.

GPS Clock Time Synchronization – The system employs an Arbiter Systems 1084B GPS satellite-controlled clock with the Network Time Protocol (NTP)/Precision Time Protocol (PTP) Server option. This allows the GPS clock to act as time server over the Ethernet network using NTP and PTP. Typical accuracy for NTP is 1 ms on a local area network (LAN). The PTP Server, GE C90^{Plus}, and F35 feeder controllers support the Institute of Electrical and Electronics Engineers (IEEE) 1588-2008 protocol assuring high-accuracy time stamping of all data and waveforms. PTP accuracy is faster than 1 microsecond.

GE Microgrid FLS Operation – The MCS continually monitors the PNS incoming utility breakers located in Franklin Substation for an islanded condition. An island condition is detected by a new F35 relay based upon tripping of the utility tie breakers by the existing utility under/over-voltage and under/over-frequency protective relays. In addition to these signals, overheat conditions from turbine generators may also be used to trigger load shed operation, but this is not programmed for the demonstration. When an island condition is detected, appropriate IEC 61850 GOOSE messages are sent to the MCS.

When the PNS power system is islanded from the local utility, the MCS will complete the actions listed in Table 2-1 (the priority of load shedding “candidates” is pre-configured):

Table 2-1. Operational Steps to Island

Step #	Step Description	Notes
1	LoU; F1 and F12 at Franklin Substation trip and/or under-frequency detected at Power Plant (PP)	
2	Main substation controller sends trip messages to feeder controllers	Using IEC 61850 GOOSE messaging
3a	PP substation breakers 8, 9, 17, and 18 tripped by fast load shedding logic in main substation controller	Separates PP from Franklin Substation and Substation 2
3b	Feeder controllers trip Substation 3 breakers 7 and 13	Separates Substation 3 from Franklin Substation
3c	PP feeder controllers trip appropriate load feeders to balance available generation	Depending on the output of the gas turbine generators (GTGs), station power requirements, and loads current being served
3d	Substation 3 feeder controllers trip appropriate load feeders to balance available generation	Same as 3c
3e	Franklin Substation feeder controller trips breakers 5, 9, and 10	Prevent back feeds through load centers
4	BESS Site Controller turns control of BESS over to D400 to charge or discharge real power to help balance available generation and support loads.	C90 ^{Plus} initiates Mode change in BESS Site Controller.
5	Emergency generator controls bring further generating units online and BESS adjusts output.	Diesel generators are automatically started and synchronized by digital control system (DCS)
6	Naval Facilities Engineering Command (NAVFAC) personnel close breakers to pick-up additional critical loads.	

To complete steps 3c, 3d, and 3e above, the MCS has up to 30 pre-defined load shedding tiers with corresponding priorities. The total power shed will be calculated from the instantaneous power loads recorded by GOOSE messages from the Universal Relay (UR) F35 relays just before the islanding event. The C90^{Plus} controller will shed the loads according to priority, until the total load shed is equal or greater than the P_{Shed} , that is:

$$\sum_{i=1}^N Load_i \geq P_{Shed}$$

Equation 1 Calculation of Number of Load to Shed

$Load_i$ is the measured real kW value of each load in the Load Shed Tier Table.

P_{Shed} is the load shed order and is based on the present online generator resources.

The shed requests are sent from the C90^{Plus} controller to the F35s, and are installed in the load substations in the form of GOOSE messages. Upon reception of the GOOSE messages, the F35s that are requested to shed load will trip their load breakers. The FLS only operates once and must be reset manually.

Phase II – BESS

Phase II included the following:

- Installation of 500 kW/580 kWh BESS of lithium-ion (Li-ion) chemistry.
- Working through the control and communication protocols needed to satisfy the rigorous requirements of ISO-NE for participation in their ancillary services markets.
- Operating BESS in a trial run on the ISO-NE signal to confirm operability.

(The following tasks were not performed due to expiration of the ISO-NE pilot program)

- Demonstrating the effectiveness of BESS in meeting ISO-NE's needs by documenting how often and to what extent the BESS resource is dispatched by ISO-NE.
- Determining the effective available capacity of a BESS given the variable requirements of the ISO that will alternately call for the charging or discharging of the system.
- Quantifying the value of the ancillary services provided so that metrics on the cost-effectiveness of this resource can be established.

Major Components (See Figure 2-2)

Battery – The battery is a Saft Intensium[®] Max 20 consisting of ten racks of Li-ion modules, each with a dedicated Battery Management System (BMS), and housed in a shipping container with an integrated heating, ventilation, and air conditioning (HVAC) and fire suppression system. The container has a central control system that communicates via Modbus to the BESS Site Controller. System energy capacity is 580 kWh.

Inverter (PCS) – Manufactured by Dynapower, this unit is capable of both charge and discharge of the battery at 500 kW with a response rate of up to 32,000 kilowatts per second (kW/s) (~500 kW/16 ms). The unit meets IEEE 1547 standards for interconnected distributed generation resources.

Site Controller – Manufactured by Dynapower, the Site Controller is the central controller for the BESS and its interface for the ISO-NE hardware and GE MCS.

Remote Terminal Unit (RTU) – The RTU is responsible for communicating market data and reliability data between the ISO-NE front-end systems and the PCS Site Controller. The system will use Modbus over the ISO-NE-dedicated Multiprotocol Label Switching (MPLS) network for communication back to ISO-NE.

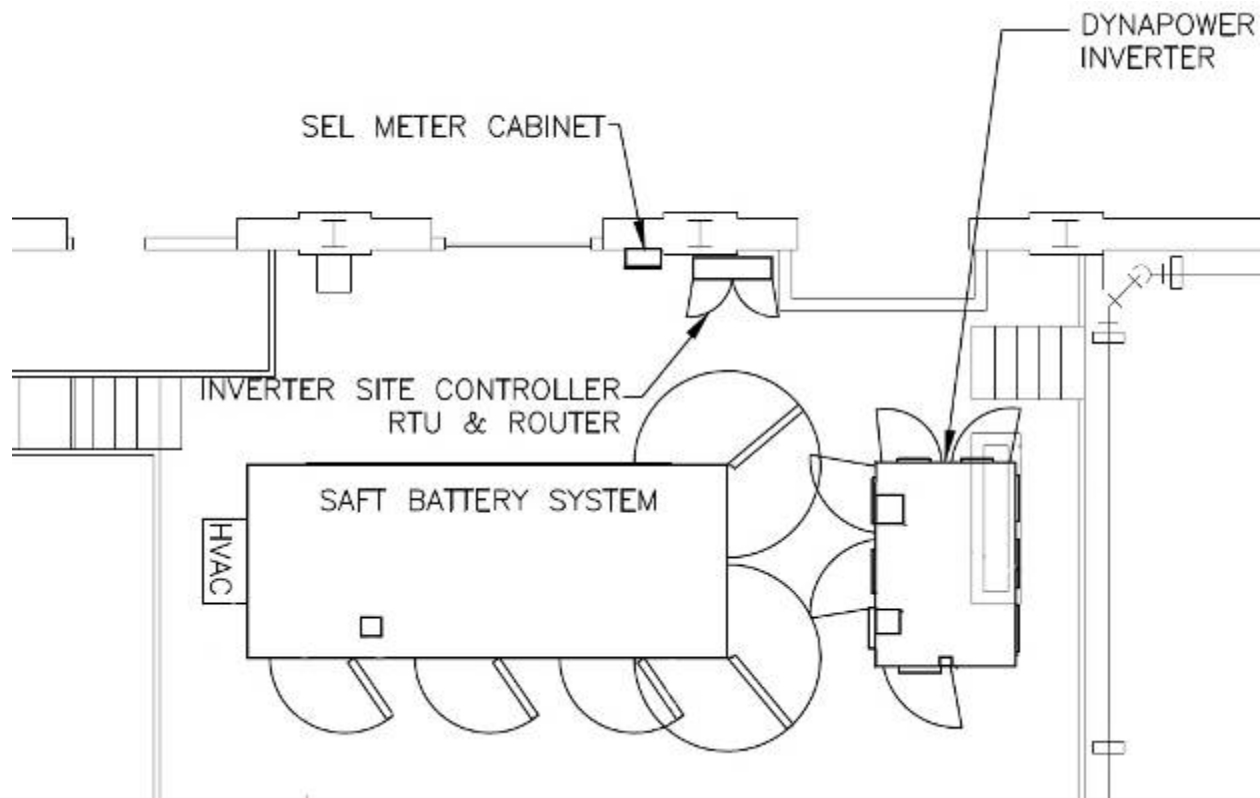
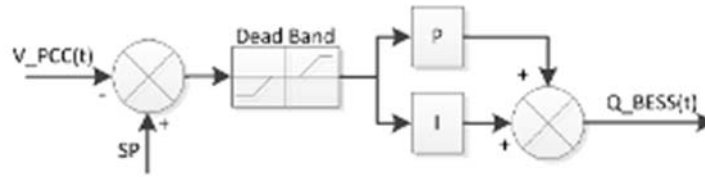


Figure 2-2. BESS Major Components

BESS Operating Modes

The Site Controller has three pre-defined operating modes. These modes can be selected through the HMI on the front of the BESS Site Controller cabinet. See drawing E-29 in Appendix G of the Final Report for the Control Block Diagram explaining the parameters for each mode of operation. The BESS operating modes are as follows:

1. **Remote Dispatch** – The BESS Site Controller provides the ability to instruct the inverter to charge or discharge the battery when requested through the ISO-NE interface and thus provide regulation up or down translated as a change in demand at the facility’s utility meter. The goal of this use case is to use the BESS for providing ancillary services to ISO-NE and participate in the non-generating resource regulation pilot program. New market rules to meet FERC Order 755 are in development. When the final rules are accepted, the pilot will end and the BESS will be available to participate as an Alternative Technology Regulation Resource (ATRR) in the ISO-NE regulation market.
2. **Automatic Voltage Regulation** – In this use case, the Site Controller commands the inverter to inject and absorb reactive power as a function of the voltage. The controller is closed-loop and derives the set point from a predefined algorithm (see Figure 2-3) that comprises a dead-band and Proportional Integral (PI) control up to the limit of the inverter and IEEE 1547 protection.



Simplified VAR Support Algorithm

$V_{PCC}(t)$ = Voltage the Point of Common Coupling
 SP = Nominal Voltage Set Point
 $Q_{BESS}(t)$ = Reactive power command to BESS

Figure 2-3. Volt-Ampere Reactive (VAR) Support Diagram

3. **Microgrid Dispatch** – The system will transition to Microgrid Dispatch mode from the Remote Dispatch mode in the event the main feed from the local utility is lost and the interconnection breaker opens initiating a transition to island mode. A ‘grid down’ relay located on GE’s C90^{Plus} indicates that the site is islanded. When in Microgrid Dispatch mode, the BESS Site Controller will receive its active power (P), and control command and ramp rate setpoints from the GE D400 controller. The BESS will maintain constant output until the diesel generator(s) are synchronized online and ready to carry the load that the BESS has been supporting. The D400 controller will then initiate a ramp down of the BESS and the BESS Site Controller will return to the previous operating mode.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Phase I – MCS/FLS

The technology applied at PNS is flexible in its application and the F35 feeder controllers provide for a very cost-effective retrofit solution. The C90^{Plus} controller is unique in that it uses hardware that has been designed to be used in utility and industrial environments and is the first controller of its type to use IEC 61850 GOOSE messaging to provide high speed, secure communications. The solution is expandable and using C90^{Plus} aggregators can load shed up to 2,500 loads.

The F35 controller also offers feeder protection capabilities that can replace ageing electromechanical and solid-state relays that are reaching their end of life. This capability was not implemented, but is under active consideration by PNS. This capability could further reduce the cost of implementing the MCS FLS while providing the facility with additional insight into power system disturbances and faults through the event logging and waveform capture capabilities inherent in these devices.

Clearly, this technology can provide the U.S. Navy, as well as other DoD facilities, with greater energy surety for their shore operations.

Over the 12-month demonstration period, PNS experienced three live events where electrical service from the local utility (Central Maine Power) failed. In two of these live events, the GTGs tripped off-line resulting in a facility-wide blackout. During Performance Verification Testing (PVT), it was demonstrated that the system functions as designed (see Section 6), resulting in a successful operation of the FLS and transition of the GTG units to island mode.

However, during a live scenario, it was determined that the utility tie-breaker protection relays are not sufficiently fast enough in detecting the fault, and in turn opening in time to protect the plant. Working with the local NAVFAC Public Works Department (PWD engineers, it was decided that there is need to install a Remote Transfer Trip between the utility tie-breaker at PNS back to the public utility's recloser located at their 34.5 kV substation approximately 3 miles away. See Section 8.0 for further details.

Phase II – BESS

The storage of energy has been in development and implementation for well over a century. One of the fastest growing and advancing technologies is solid based chemistry batteries. There are numerous companies within this sector that have decades of proven manufacturing experience and success in producing standardized cells. Within the past 20 years, the battery industry has made great strides in increasing both energy density and life-cycles while also providing higher rates of charge/discharge, predominately made possible by the advancement of Li-ion chemistry.

Figure 2-4 depicts the many forms of energy storage available on the market today, showing the operating characteristics and preferred applications for each.

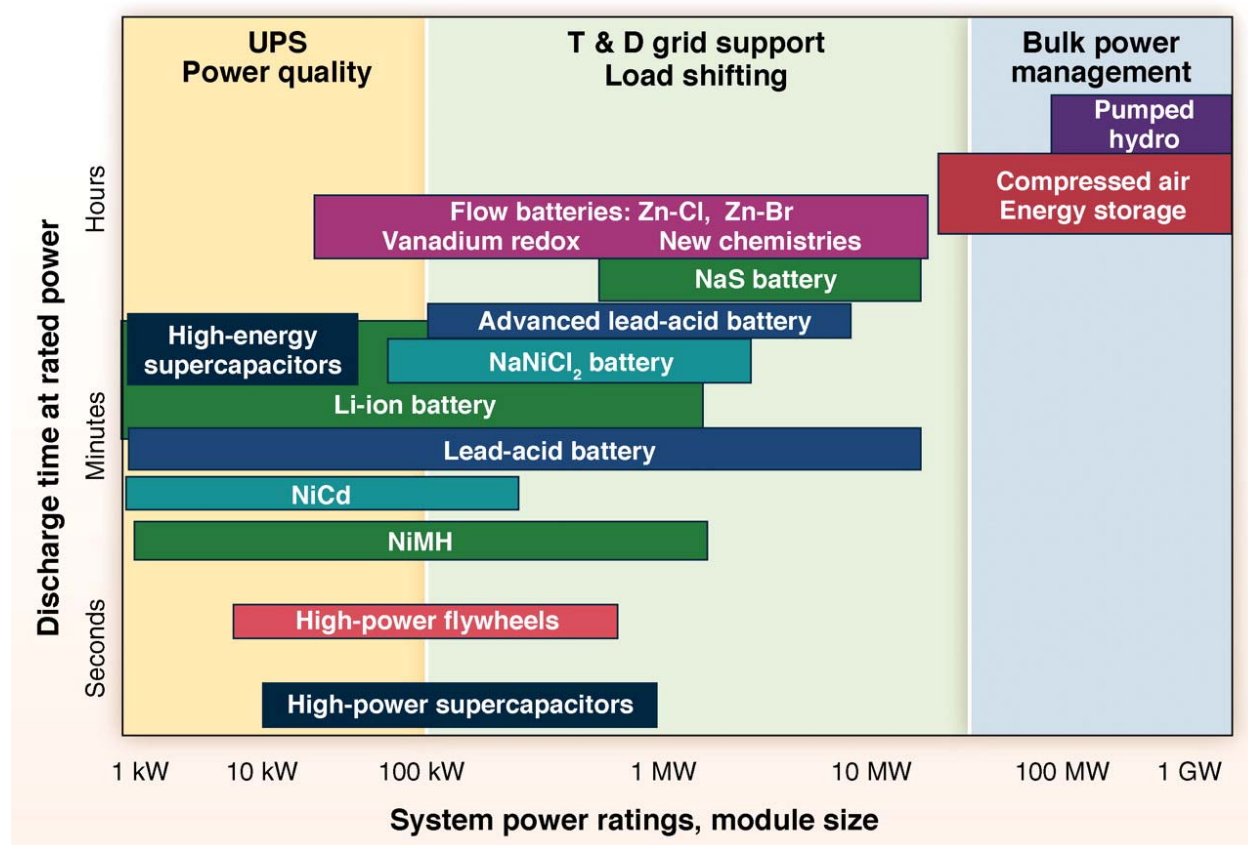


Figure 2-4. Energy Storage Technology Range of Application

(Utility Scale Energy Storage Systems: Benefits, Applications and Technologies, State Utility Forecasting Group, Purdue University, June 2013)

Li-ion was selected for this demonstration, keeping in mind the application at hand, which is to provide interim emergency back-up power during an islanding event (Phase I) and participate in the ancillary services market, specifically the ISO-NE pilot program running on frequency regulation (Phase II), both of which require dispatch in sub-hour time frames.

Regarding alternative technologies, advanced lead-acid and sodium sulfur (NaS) chemistries were researched and considered, both of which may have been capable of meeting the operating profiles we desired for this application and coming in within budget. However, both companies that were sourced for pricing during the time of development subsequently experienced either critical cell level failures or changes in design that ultimately resulted in discontinuation of those products or even bankruptcy of the manufacturer. Other manufacturers of these chemistries exist and are worth watching for future development; however, there have been steady and dramatic decreases in the cost of Li-ion-based systems specifically just over the three years since the kick-off of this demonstration and this trend is expected to continue. Flow batteries may be another promising chemistry to consider in future projects, with this technology maturing and coming down in cost, although it must be noted that the optimum operating profile for this chemistry is multiples of hours at a low rate of discharge relative to its storage capacity, which does not meet the needs of the applications in this demonstration.

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3.0 PERFORMANCE OBJECTIVES

Phase I – MCS/FLS System

The primary metric for a successful deployment of the FLS system is based upon keeping the Power Plant online through transition to island mode following an LoU event. A secondary metric of success is the ability of the islanded system to maintain electric service to mission-critical loads at the Shipyard. The HMI affords the Operator the ability to prioritize the tripping/non-tripping of the Shipyard loads at the Power Plant and Substation 3. This gives the Operator the flexibility to adjust the FLS to match the day-to-day Shipyard operations schedule. The demonstration will monitor and measure proficiency of the MCS to match load to capacity (MW), success of MCS to FLS (measured in speed of response in milliseconds), and BESS participation in transition to island mode (enabled/not enabled in FLS calculation, measured load maintained/shed).

The system's effectiveness in eliminating Power Plant outages will determine how much downtime is avoided in a given year from loss of public utility outages. Additional savings related to Annual Avoided Cost (AAC) in lost productivity (\$) will be estimated. This measurement can be used to justify the upfront costs to implement the FLS system at a given facility based on the value of the services that facility provides. A facility's operational requirements (energy surety of critical loads versus use of reserve margin to serve non-critical loads) will ultimately determine this value. For example, the FLS allows for the inclusion of a reserve margin for a generator that is online. If this margin is set to zero, then more load will be shed to maintain energy surety. This setting is user selectable. A consideration in establishing this margin is the response time of the generators to pick up additional steady state load. This requires stability studies to be performed to establish whether the generator control response is fast enough to support the steady state load requirements of the island.

Table 3-1. Performance Objectives, Phase I – MCS/FLS

Performance Objective	Metric	Data Requirements	Success Criteria
Quantitative Performance Objectives			
Energy Security	Power Plant Non-Trip for LoU event	Document Power Plant Trip/Non-Trip for LoU	The Shipyard successfully islanded without Power Plant trip for each LoU event tested during the two PVT simulated tests and the two live tests.
Proficiency of MCS to Maintain Generation – Load Balance for LoU	Power Values (MW)	Pre-/Post-LoU Power measurements for all monitored breakers, breakers tripped, generating units online, and FLS settings established by Shipyard	The MCS trips sufficient load to maintain steady state Generation – Load Balance for LoU. The summer configuration (1 GTG) was tested and the FLS correctly tripped a total of 1,161 kW of load at the Power Plant and Substation 3. See C90 ^{Plus} Event Log and HMI Screen Shot. The winter configuration (2 GTGs online) was tested and no additional load was required to be tripped at the Power Plant or Substation 3 as the online generation was sufficient to support the connected load. See C90 ^{Plus} Event Log and HMI Screen Shot.

Table 3-1. Performance Objectives, Phase I – MCS/FLS (Continued)

Performance Objective	Metric	Data Requirements	Success Criteria
Demonstration of Fast Load Shedding	Time (ms)	Document time to trip from detection of LoU	Trip command <3.0 ms, overall trip time <2.1 + breaker trip time <50 ms. (Power Plant and Substation 3 were islanded and all loop and load breakers were tripped in <50 ms. See the Waveforms for each Test. The total trip time, including the delay caused by an auxiliary relay at Franklin, was <80 ms.
AAC of Lost Production	Number of events per year, value of lost Shipyard production per event	History of lost production costs for LoU events	The simple payback of the system is greater than or equal to the useful life of the FLS system.
BESS Participation in Transition to Island Mode	Power (MW) and time (ms) of response, and additional load maintained	MCS control actions, BESS status, response time, BESS kW	The MCS successfully dispatched the BESS following LoU during the simulated tests, acting as a “Buffer.” The BESS was bypassed during the live tests. Follow-up testing was performed to demonstrate the BESS operating as a “Bridge,” though the BESS dispatched the FLS program failed to take the additional capacity of the BESS into consideration with the load shed priority calculations. GE identified the error in calculation and formulated a corrective action to alter the programming to resolve the issue. Due to time constraints and logistical challenges of receiving approval to perform follow-up testing, the re-programming has not been performed to date but is planned to be implemented during the next phase of build out in the upcoming Energy Savings Performance Contract (ESPC).
Qualitative Performance Objectives			
Ease of Use	Operator Success in Learning the System	Interview PNS Personnel	NAVFAC personnel have gone through training and were responsible for operation/monitoring of the system over the 12 month demonstration period.
Operational value of MCS/FLS	Degree of Satisfaction	Interview PNS Personnel	Overall, the Operators have come to value the capabilities of the MCS/FLS, in particular the additional generator/load data provided by the HMI in the control room. Though PVT proved operability of the FLS, live events over the demonstration period proved that additional components on the utility tie-breakers are needed to successfully island consistently. Only one out of four live events resulted in a successful transition to island mode.
Transferability of MCS-FLS application to other DoD sites	Review of Solicitations and Projects Underway	Industry Awards and Projects out for Solicitation	Ameresco is presently developing three ESPCs, which include MCS/FLS and BESS technology, including another phase at PNS. Increasingly, ESPC solicitations are coming out with microgrid technologies specified.

Phase II – BESS

The overall objective of this phase is to demonstrate the capability and benefits of a BESS participating in ancillary services. The technical requirements include automated control and communication of the BESS with an ISO. The benefit in turn is the generation of revenue through payments from the ISO, which can in turn create an annuity to be applied in payback of the investment. This positive cash flow may provide the opportunity for performance contracting such as Energy Savings Performance Contracts (ESPCs) or Power Purchase Agreements (PPAs). Performance objectives for Phase II are listed in Table 3-2. See Section 7.0 for further details.

Table 3-2. Performance Objectives, Phase II – BESS

Performance Objective	Metric	Data Requirements	Success Criteria
Quantitative Performance Objectives			
BESS Automatic Response Rate	MW per minute (min)	Logging with D400 and/or Power Quality Meter	100 MW/min
BESS Hourly Performance	%	ISO-NE Reports	95%
Revenue Generated from BESS in Regulation	\$	ISO-NE Reports	Approx. \$8,000/month or \$100,000/year
Qualitative Performance Objectives			
Ease of Operational Use of BESS with ISO-NE	Operator Success in Learning the System	Switch Board Operator Feedback	Ability for Operator with limited training to operate the system.
Transferability of BESS to Operate at other sites	Market Outlook	ISO/RTO, State, and/or Utility Policies	Regions encouraging participation of energy storage on grid.

Two metrics that determine the amount of revenue that will be generated in the ISO-NE regulation market are Automatic Response Rate (MW/min) of the BESS and its Hourly Performance (%). Multiplying these measurements by the capacity (MW) bid into the market will result in a Revenue Generated (\$). These metrics will be useful in determining the feasibility of technology transfer at other bases within the ISO-NE region, as well as the greater ISO/RTO regions throughout the United States with similar markets, such as PJM, NY-ISO, MISO, ERCOT, and CAISO (see Figure 3-1).

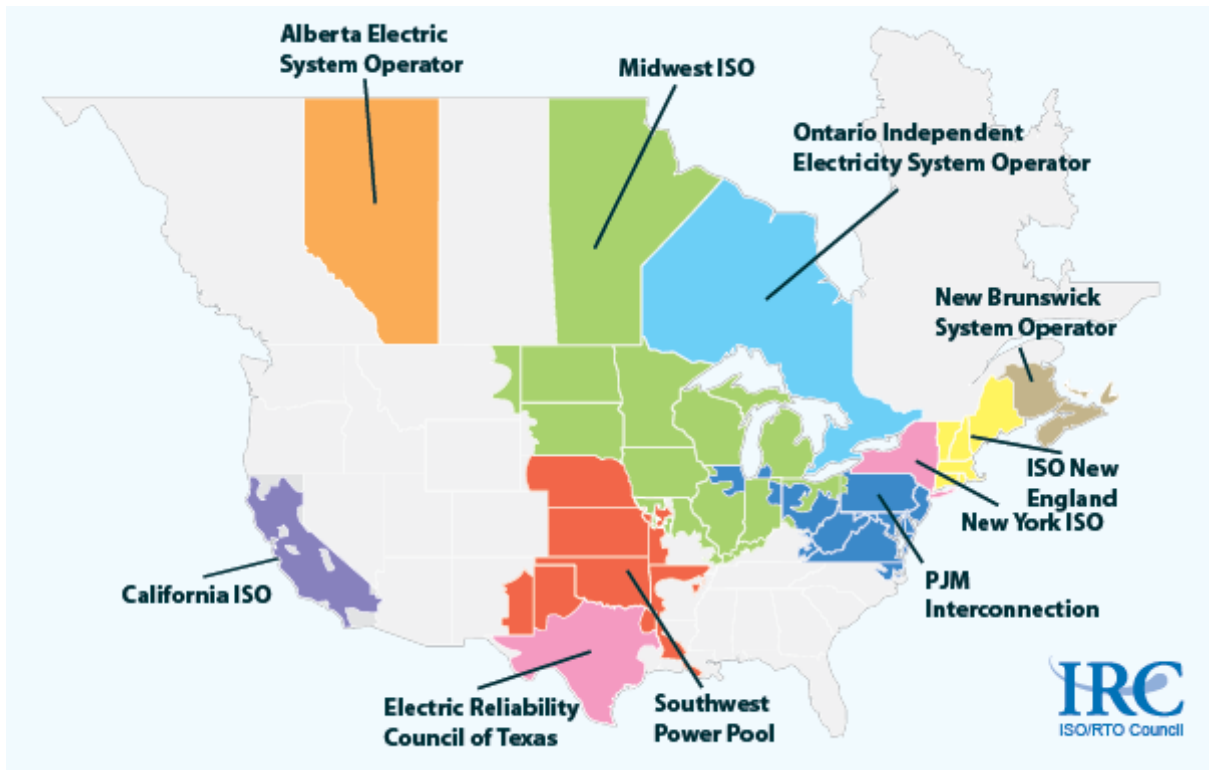


Figure 3-1. Deregulated Electricity Markets

4.0 FACILITY/SITE DESCRIPTION

Portsmouth Naval Shipyard is a Navy facility located in Kittery, Maine. Founded in 1800, the Shipyard has a long history of supporting the Navy fleet, from building tall ships such as the USS Constitution, to the first submarines implemented in WWI and diesel subs for WWII, transitioning to nuclear during the Cold War. Today, the Shipyard supports the retrofit and refueling of the U.S. Navy's fleet of fast-attack submarines, including the Los Angeles and Virginia class.

This demonstration focuses on the Shipyard's electrical generation and distribution infrastructure. The BESS and predominant equipment for the FLS/Microgrid will be housed at the Power Plant (Building 72). Additional FLS hardware and fiber optic communications will be installed on the 13.2 kV electrical distribution grid at Substation 3 (Building 175) and Franklin Substation (Building 321).

4.1 FACILITY/SITE LOCATION AND OPERATIONS

Ameresco designed, implemented, financed, and now operates and maintains the PNS Power Plant under an ESPC with the Navy. The team includes onsite fulltime staff who are intimately familiar with the Shipyard's mission requirements and facility infrastructure and operations. This assures the proper integration of the work of this study and close onsite monitoring of performance throughout the implementation and test periods. Figure 4-1 depicts PNS. The red box indicates the bounds of this demonstration including both Phase I – MCS/FLS and Phase II – BESS systems



Figure 4-1. PNS Demonstration Area

Figure 4-2 provides a closer view of the demonstration site, which includes the Power Plant, Substation 2, Substation 3, and Franklin Station. Phase I of the demonstration will implement the FLS system that will be installed with components being located at the Power Plant, Substation 3, and Franklin Station. Through these controls, the Shipyard will have the capability to select a priority list for the descending order in which loads should be shed—non-essential to mission-critical. First and foremost, loads that support operation of the Power Plant will be kept online at all times, followed by select feeders located at the Power Plant and Substation 3, which provide power to the dry docks and/or other mission critical buildings. Franklin Station and Substation 2 will be isolated with all power being cut during an islanding event.

Phase II will focus on the BESS, which is located at the Power Plant on the 480V station service bus. Power is transferred from the BESS to Franklin Station via a 13.2 kV loop feeder, which then is stepped up to 34.5 kV at the point of interconnection with the local utility. Section 5.3 addresses this architecture in further detail.

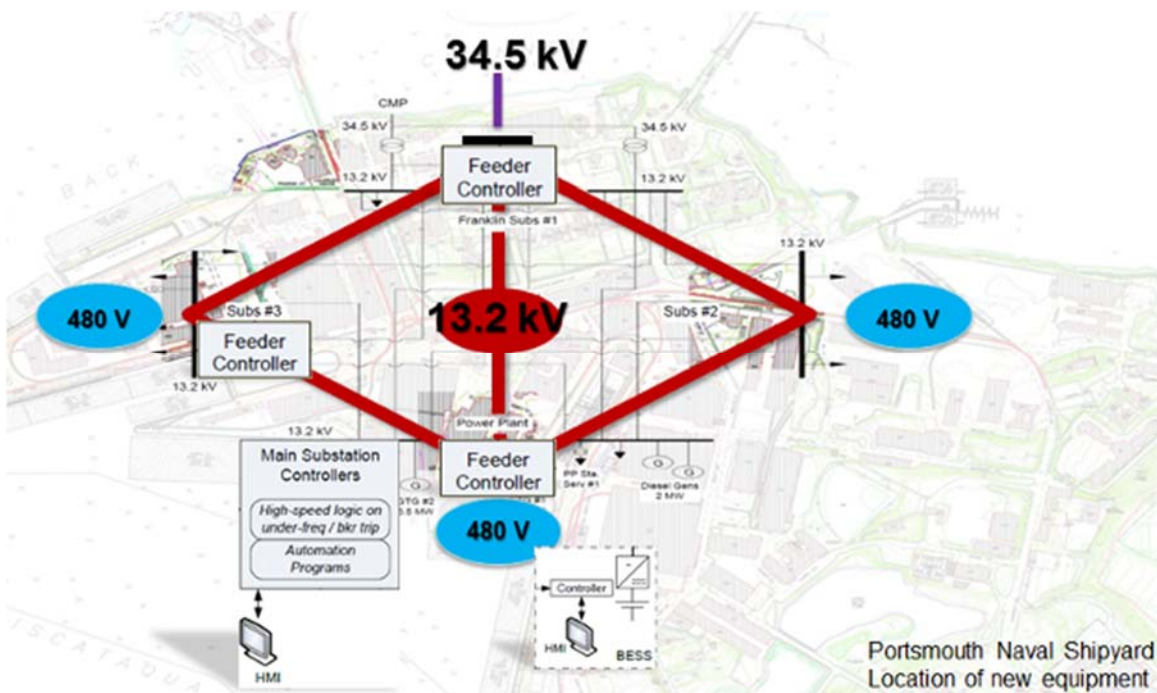


Figure 4-2. Demonstration Site

4.2 FACILITY/SITE CONDITIONS

Portsmouth Naval Shipyard installed a 10 MW gas-fired combustion turbine cogeneration plant as part of a comprehensive ESPC executed in two phases between 2000 and 2002. The Power Plant can operate in parallel with the Central Maine Power (CMP) utility grid or in island mode and includes: two 5 MW solar combustion turbines, each with Heat Recovery Steam Generators (HRSGs) rated at 65,000 pounds per hour (lb/hr) each with supplemental fire, two 70,000 lb/hr packaged steam boilers, two 1.5 MW diesel emergency generators that support “black-start,” and a dedicated SCADA system. The Power Plant provides energy security (both electricity and steam) for mission-critical nuclear submarine activities on-base while also producing significant energy and operating cost savings for PNS.

Loss of Grid Power and Re-Start Delay. The Power Plant provides back-up power to mission-critical systems at the Shipyard when power is lost from the CMP utility grid. If the Shipyard's total electrical demand (kW) is greater than the capacity of the operating turbine(s) when grid power is lost, then the turbine(s) become overloaded and trip out. This scenario historically occurs two to three times a year due to weather events and other factors. When this happens, plant Operators must manually disconnect non-critical loads throughout the Shipyard and restart the turbines. This process takes between one to three hours, during which time the entire Shipyard is without power, except for isolated loads served by emergency generators and uninterruptible power supply (UPS) systems. This vulnerability has become more pronounced in recent years as the Shipyard's peak electrical demand has grown (due to growth in mission) from approximately 12 MW in 2000, to >16 MW today.

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5.0 TEST DESIGN

Phase I – MCS/FLS

Fundamental Problem: The DoD community has recognized that the aging infrastructure of the commercial power grid has resulted in frequent power outages. Portsmouth Naval Shipyard experiences two to three such outages each year. These outages have resulted in the tripping of the Shipyard generating plant with outages of one to three hours.

Demonstration Questions: Can an FLS solution eliminate the outages experienced by the Shipyard while maintaining energy surety for mission-critical loads? Will the AAC of lost production pay for the cost for the FLS solution? Can the MCS/FLS effectively utilize BESS technology to maximize the amount of load served?

Phase II – BESS

Fundamental Problem: Multiple value streams can be associated with the implementation of an energy storage system, such as generating additional revenue through participation in ancillary services and avoided costs in Loss of Productivity; it is the purpose of this demonstration to quantify these values.

Demonstration Question: What is the breakeven point where the upfront cost of the technology plus the revenue from ancillary services and savings in avoided Loss of Productivity equals the economic life of the system?

5.1 CONCEPTUAL TEST DESIGN

Hypothesis: The combination of implementing an FLS system and BESS with existing onsite generation can reduce and even eliminate facility-wide blackouts at a base while also creating new value streams in the form of revenue from participation of the BESS in ancillary services (specifically frequency regulation) and avoided costs related to Loss of Productivity during an extended outage.

Phase I – MCS/FLS

Independent variable: The independent variable for MCS/FLS is the calculated value of self-generation including pre-defined margins available to support Shipyard load following the LoU event. The real measured value of the loads are then summed, based upon the Operator-defined priorities, until that sum is less than or equal to the available generation post-LoU. The remaining loads are then tripped in high speed. The end-to-end trip execution time for the FLS is expected to be 15–20 ms.

Dependent variable(s): The pre-LoU event values of power for the tripped loads at the Power Plant and Substation 3 will be evaluated against the settings in the C90^{Plus} to validate the power balance calculation.

Controlled variable(s): The existing utility tripping scheme is monitored by the MCS/FLS. It has not been modified so as to allow a valid comparison of the MCS/FLS with past events. Further, all loads at Franklin Substation and Substation 2 have been excluded from the generation- load power balance calculation.

Test Design: See Appendix B of the Final Report, Performance Verification Test (PVT) plan.

Test Phases: See Appendix B of the Final Report, Performance Verification Test (PVT) plan.

Phase II – BESS

The BESS did not participate in the market in 2014–2015, due to delays in signing of the interconnect agreement between the utility and the Shipyard. What follows was the implementation plan for that approach.

Independent variable: A BESS consisting of a 500kW PCS and a 580 kWh Li-ion battery will be introduced to the PNS electrical grid behind the meter and used to participate in the ISO-NE regulation market.

Dependent variables:

1. *Regulation Clearing Price (RCP)* is set in the ISO-NE bid market. For the demonstration period, the system will serve as a price taker and will not attempt to influence the clearing price.
2. *Time ON Regulation* is the unit of time in minutes that the system operates within a given hour.
3. *Fade Time* is the unit of time in minutes that the system reaches an upper or lower limit in State of Charge (SOC), which prevents the BESS from continuing to provide Regulation service.
4. *Regulation Service Megawatts* is the sum of the absolute value of positive and negative movement that would occur if the resource responded at its Automatic Response Rate without delay in pursuit of changing Automatic Generator Control (AGC) setpoints while providing Regulation within the hour, known also as “mileage.”

Controlled variable: Participation in ISO-NE regulation market will be broken into one-hour blocks of participation with the intent to operate as many hours as possible for the duration of the demonstration period. The target will be operation 24/7 for a period of four months from December 2014 through March 2015.

Test Design: The BESS will be allowed to run on the ISO-NE regulation market 24/7 over a four-month period beginning December 1, 2014, and ending March 31, 2015. Success in performance of the system for Phase II will be measured in the BESS’ ability to create a new revenue stream through participation in ISO-NE’s regulation market. The revenue generated by the BESS in Regulation can then be used in part to determine the economic value of investing in the technology when comparing the following metrics.

5.2 BASELINE CHARACTERIZATION

Phase I – MCS/FLS

Reference Conditions:

1. Number of LoU events causing tripping of Power Plant
2. Length of outage for each event
3. Cost of lost production for each event
4. Power Plant power output at time of event
5. Other significant issues due to outages

Existing Baseline Data: Obtain outage records from NAVFAC.

Baseline Estimation: The Principal Investigator (PI) will research the operational records for the Shipyard to establish the number of historic LoU events. The PI will establish the length of each outage. The PI will work with Shipyard Operations to establish an estimated hourly cost and the average load in MW being served. This data will allow for the calculation of a yearly cost, or AAC, for LoU events.

Data Collection Equipment: The FLS system will utilize GE F35 feeder protection relays to collect generation and load data by measurement of power, voltage, and current. The F35 provides an economical retrofit solution for existing switchgear as one F35 can monitor a single bus voltage and the currents for five circuit breakers or two bus voltages and current from four feeders. The D400 gateway will monitor the status of the BESS and the charge/discharge power of the BESS for inclusion in the FLS calculations by the C90^{Plus} FLS controller.

Phase II – BESS

Reference Conditions:

1. RCP
2. Battery SOC
3. AGC Signal

Existing Baseline Data: Historic RCPs can be obtained from ISO-NE's website. See Figure 5-1 in the Final Report for further examples.

Data Collection Equipment:

1. GE D400: This unit will be used to log data at the Modbus communication level between the RTU, Site Controller, PCS, and battery. The pointlist is extensive and covers more parameters than are expected to be relevant for the demonstration analysis; however, all operating data will be captured since the D400 contains sufficient memory to do so.
2. Schneider Electric Laboratory Solutions SEL-735: This power quality and revenue grade meter serves two purposes in the demonstration: (1) to report system response performance in kW back to ISO-NE with 0.3% accuracy in 4-second intervals, and (2) to log data useful for baseline and performance measurements such as the kW response and power quality metrics like voltage, amps, frequency, and n^{th} harmonics.



SEL SEL-735 Power Quality and Revenue Meter



The SEL-735 meter combines leading power quality capabilities with exceptional revenue metering accuracy at an economical price. Power quality reports with IEC 61000-4-30 compliance help identify and troubleshoot problems in power system equipment. Advanced communications deliver critical and historical information in real time to virtually any communications system. The SEL-735 is the essential meter for substation, power plant, and industrial metering.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

Phase I – MCS/FLS

System Design: An MCS consisting of an FLS scheme is being implemented to detect an LoU event and initiate fast load shedding to maintain power balance for the Shipyard. The FLS consists of a C90^{Plus} FLS controller that calculates power balance for the Power Plant and Substation 3 of the Shipyard. The loads served by Franklin Substation and Substation 2 were excluded in the demonstration to minimize the installed cost of the MCS/FLS. F35 feeder controllers are installed on key circuit breakers at the Power Plant and Substation 3. These F35s monitor the breaker real-time status and power measurements and communicate them to the C90^{Plus} FLS controller via IEC 61850 GOOSE message.

Components of the System: The MCS/FLS consists of the following major components. All of these components are commercially available and have been applied in customer facilities.

GE Multilin C90^{Plus} FLS Controller: The controller is the main decision point of the system where all the calculations and intelligent commands are sent. It is a substation hardened device with a real-time operating system that is highly reliable and accurate. It is also equipped with a local annunciator panel and HMI screen (optional) for ease-of-use for maintenance and operation and embedded IEEE 1588 time synchronization protocol support. The controller receives source and load data from the F35 via analog GOOSE. The load shed commands are issued via GOOSE to end devices. The C90^{Plus} controller is installed in a rack at the Power Plant with the F35 relays.



GE Multilin F35 Feeder Protection Relays: The FLS utilizes the F35 feeder protection system to provide feeder protection, control, monitoring, and metering in an integrated, economical, and compact package. The F35 provides a cost-effective solution as the F35s are configured to protect up to five feeders with bus voltage measurement. It also provides fast and deterministic execution of programmable logic, which is necessary for substation automation applications. The F35s have embedded IEEE 1588 time synchronization protocol support over Ethernet.



GE Multilin D400 Data Gateway and Controller: GE's Multilin D400 is a secure, hardened, advanced substation gateway that collects metering, status, event, and fault report data from serial or LAN-based intelligent substation devices and accepts time sync signals from Simple NTP (SNTP)/NTP servers. The Multilin D400 summarizes data from the substation devices and makes it available locally/ remotely through a standard secure web browser (Hypertext Transfer Protocol Secure [HTTPS]). It supports serial and/or LAN connections to SCADA masters.



- The Multilin D400 provides the computing platform necessary to automate substation procedures, such that intricate processes are carried out safely and efficiently by creating custom automation programs using IEC 61131 compliant tools, and performs basic math functions on data points using the built-in calculator tool. Using pass-through connections, users can extract valuable non-operational data such as digital fault recording (DFR) records, event, and oscillography files. The user can also access the historical log files and upload the archived data for trending and analysis.

GE Multilin ML3100 Managed Ethernet Switch:

The MultiLink ML3000 Series of managed Ethernet switches provides extremely reliable networks, and the SMART RSTP feature allows for recovery from faults in ring network architectures in <5 ms per switch in the network—10 times faster than generally available in standard Ethernet. The complete set of network management functions available provides the configurability and monitoring capability needed for most applications, while the high level of security features available ensures the network is protected from tampering or illegal access. The ML3100 series supports the end-to-end transparent clock, boundary clock, and ordinary clock as specified in the IEEE 1588v2 standard. Ambient operating temperature is -40°C to +85°C without fans.

**Arbiter Systems® 1084B GPS Satellite-Controlled Clock:**

The overall time synchronization of the MCS/FLS components is affected by the application of the Arbiter 1084B clock with GPS satellite antenna. The Model 1084B provides the most-needed GPS system clock features in an economical package and adds a liquid-crystal display (LCD) setup/status display and keyboard. The clock is equipped with an NTP/PTP server option that allows the Arbiter clock to act as a time server over an Ethernet network using the NTP and the PTP. The PTP server supports the IEEE 1588-2008 protocol and functions as a grandmaster clock. NTP accuracy is better than 100 microseconds and PTP accuracy is better than 1 microsecond.



Dell™ PowerEdge™ 720xd 2ru Rack-Mounted Server: Equipped with a 2.5 gigahertz (GHz) Intel® Xeon® CPU, 16 GB random access memory (RAM), 750-watt (W) power supply, 2 hot swappable 1 terabyte (TB) Serial Advanced Technology Attachment (SATA) hard disk drive (HDD) with RAID 1, and Dual 1 GB Network Interface Card, Microsoft Windows Server 8. A separate 42-inch LG light-emitting diode (LED)-backlit LCD display panel is being provided.



Software for the HMI and data storage includes the following:

GE Power Management Control System (PMCS)/CIMPLICITY 9.0 SCADA Software:

Based on decades of GE innovation and award-winning Proficy HMI/SCADA – CIMPLICITY 9.0 delivers a proven platform to precisely monitor and control every aspect of the MCS environment, equipment, and resources. CIMPLICITY improves the structured database quickly and easily, enabling Real-time Operational Intelligence—for the right information, anytime, anywhere.



With Version 9.0, longer point names can be created including alarm, event, and action identifications with up to 256 mixed case characters. The more descriptive database, improved tree views, and richer objects result in better interaction with newer protocols, ease of maintainability, improved modeling, and a richer experience.

Keeware® KEPServerEX®: the industry's leading communications platform that leverages OLE for Process Control (OPC) (the automation industry's standard for interoperability) and information technology-centric communication protocols (such as Simple Network Management Protocol [SNMP], Open Database Connectivity [ODBC], and web services) to provide users with a single source for industrial data. Designed around the four product pillars of Proven Interoperability, Centralized Communications, On-Demand Scalability, and Industrial Strength, KEPServerEX is developed and tested to meet customers' performance, reliability, and ease-of-use requirements. It is equipped with Modbus Suite for high-speed data retrieval of real-time power system values and alarm events from the GE devices.

GE EnerVista™ Integrator: enables seamless integration with GE's Multilin devices for new or existing automation systems through tested, pre-configured memory maps. EnerVista Integrator reduces the setup and commissioning efforts required to obtain device, event, and waveform data by >90% for integration with an HMI, SCADA, or DCS system.

System Depiction: See Figure 5-1 and Appendix E of the Final Report for a system architecture diagram.

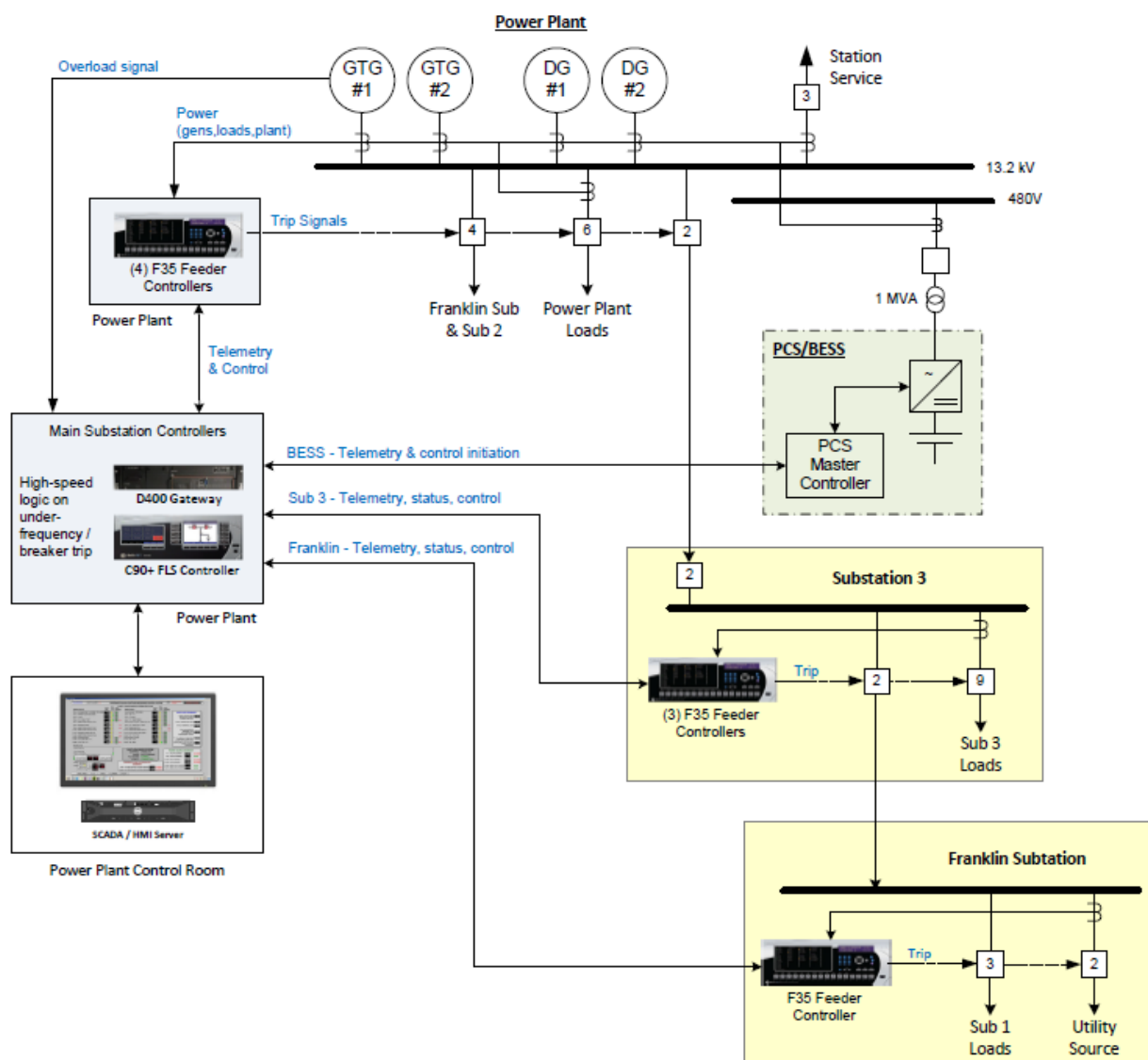


Figure 5-1. System Architecture Diagram

Phase II – BESS

System Design: The PNS electrical grid infrastructure consists of two major substations (Substation 2 and Substation 3), a combined heat and power (CHP) Power Plant, and an interconnection with the public utility (Franklin Substation). These four stations are connected at the 13.2 kV via loop feeders with each station then distributing 480V service to various loads on the yard. As shown in Figure 5-1, the BESS is located at the Power Plant as depicted within the dashed line box. A full-size drawing can be found in Appendix E of the Final Report.

The system consists of a 500 kWh Li-ion battery, 500 kW PCS, Site Controller, RTU, and router providing communication to/from ISO-NE across an MPLS network.

Components of the System:

580 kWh Li-Ion Battery – Manufactured by Saft America, the IM20 unit is built on a containerized platform. The container is populated with 10 battery strings wired in parallel, with each string consisting of 28 modules wired in series. The unit is self-contained and includes the HVAC and fire suppression systems necessary for safe operation. Auxiliary power for the battery management, HVAC, and fire suppression system are fed separate from the battery via independent 480V and 120V service fed from house power.



500kW PCS – Produced by Dynapower, this unit houses an Inverter, Rectifier, and Isolation Transformer that serve to charge/discharge the battery from/onto the electrical grid at a 480V 3 Phase level. The unit is actively liquid cooled and includes a top-mounted liquid/air heat exchanger. Auxiliary electronics, fans, and pumps are powered internally via the PCS' 480V connection on the station service bus.



Site Controller – Also manufactured by Dynapower, this unit consists of a CPU, analog input/output (I/O) board, digital I/O board, Ethernet hub, and HMI touchscreen. This is the primary interface for manual and remote operation of the BESS. From this point, operator commands and system limits are processed based on data collected from the Battery and PCS. It also houses the ISO-NE communications hardware, which includes the RTU and router.



RTU – The RTU selected for this project is manufactured by OSI. The model is the OSIRIS™ and comes with a number of different communication ports including Digital I/O, Analog Inputs, Serial, and Ethernet ports. The unit is connected solely by Ethernet and serves to translate the Modbus communications coming from the Site Controller to Distributed Network Protocol (DNP3), which is then relayed to the router for communication to ISO-NE.



Router – The Cisco® 1941 series router is supplied by ISO-NE and serves as the primary connection and firewall to the dedicated MPLS network. Data packages containing operating commands and performance information are received and sent in both directions between the BESS and ISO-NE. This is a live connection with a 4-second sample rate. Included in the router is a 3G wireless Enhanced High-Speed WAN Interface Card (EHWIC), purposed as a backup form of communication to/from ISO-NE in the event of a failure of the land-based circuit.



Power Quality Revenue Meter – ISO-NE requires a power quality meter that can report within 0.3% accuracy performance of the regulation resource, i.e., BESS. The SEL-735 is programmed to communicate via Modbus over Ethernet with power in kW to the RTU, which is then translated via the Cisco router back to ISO-NE. The Current Transformers (CTs) for this unit are installed between the PCS and station service bus, effectively reporting the “gross” power response, which includes the auxiliary power necessary to operate the PCS. See Figures 5-4 and 5-5 of the Final Report for further installation details.

SEL-735 Power Quality and Revenue Meter



The SEL-735 meter combines leading power quality capabilities with exceptional revenue metering accuracy at an economical price. Power quality reports with IEC 61000-4-30 compliance help identify and troubleshoot problems in power system equipment. Advanced communications deliver critical and historical information in real time to virtually any communications system. The SEL-735 is the essential meter for substation, power plant, and industrial metering.

System Integration: The BESS is tied into the existing 480V station service bus by breaker 52G as seen in Figure 5-1. Detailed design drawings can be found in Appendix G of the Final Report.

5.4 OPERATIONAL TESTING

Phase I – MCS/FLS

Operational Testing of Cost and Performance: The MCS/FLS will collect power, voltage, and current values for the monitored circuit breaker. The F35 relays are mounted in racks and the phasing and measured values were verified during Factory Acceptance Testing.

Modeling and Simulation: No modeling or simulation will be performed.

Timeline: The MCS/FLS solution underwent Site Commissioning and Performance Verification Testing per the schedule shown in Table 5-1:

Table 5-1. MCS/FLS Commissioning and PVT Schedule

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
9/7/2015	9/8/2015	9/9/2015	9/10/2015	9/11/2015	9/12/2015
Holiday	Travel	<=====Pre-Commissioning=====>			
9/14/2015	9/15/2015	9/16/2015	9/17/2015	9/18/2015	9/19/2015
<=====Site Commissioning=====>					Off
9/21/2015	9/22/2015	9/23/2015	9/24/2015	9/25/2015	9/26/2015
<=====Site Commissioning=====>					Off
12/7/2015	12/8/2015	12/9/2015	12/10/2015	12/11/2015	12/12/2015
Prep	<=Performance Verification Testing=>			Debrief	Off

See GE Site Commissioning Plan (SCP) and PVT plans included in Appendix B of the Final Report.

Phase II – Operation of BESS in ISO-NE Regulation Pilot

Installation of the BESS commenced in April 2014, and was completed in May 2014. Participation in the ISO-NE Regulation pilot was to commence once an Interconnection Agreement (IA) as expected to run 24/7 from mid-December through March 31, 2015 (see Figure 5-2).

	May 2014		June 2014		July through Nov		December 2014		January 2015		February 2015		March 2015	
Week	1-2	3-4	1-2	3-4			1-2	3-4	1-2	3-4	1-2	3-4	1-2	3-4
BESS Installation														
BESS Commissioning														
Interconnection Agreement Navy/Utility														
BESS Online ISO-NE Regulation Pilot														

Figure 5-2. BESS Installation through Demonstration Schedule

Though system checks while connected to ISO-NE were performed and successful operation was confirmed, a signed IA between the Navy and CMP was not obtained in time for participation in the ISO-NE pilot program.

(The IA and modified Navy contract with CMP can be found in Appendix F of the Final Report.)

5.5 DATA COLLECTION

The data collected for the MCS/FLS events originates from the C90^{Plus}, F35s, D400, and HMI server. The F35 provides the real-time information for the monitored circuit breakers. The F35 also provides detailed records of the measured values, receipt of trip command from the C90^{Plus}, and waveform (oscillography and data logger information). The HMI server screen provides the Operator with a complete picture of the system (see Figure 5-3). Key summaries include: FLS System Status, Load Shed Summary, Load Breaker Status (Open, Local/Remote, Load Values, Shed Priority), Minimum Load to Maintain (Station Service Load), and Power Source Summary (Utility, GTGs, Diesel Generators [DGs], and BESS). The HMI server screen also provides the means of assigning loads priorities, enabling/disabling the MCS/FLS, enabling the inclusion of the BESS in the FLS calculation, and displaying an expected value of load to be shed.

Further detail can be found in the Final Report.

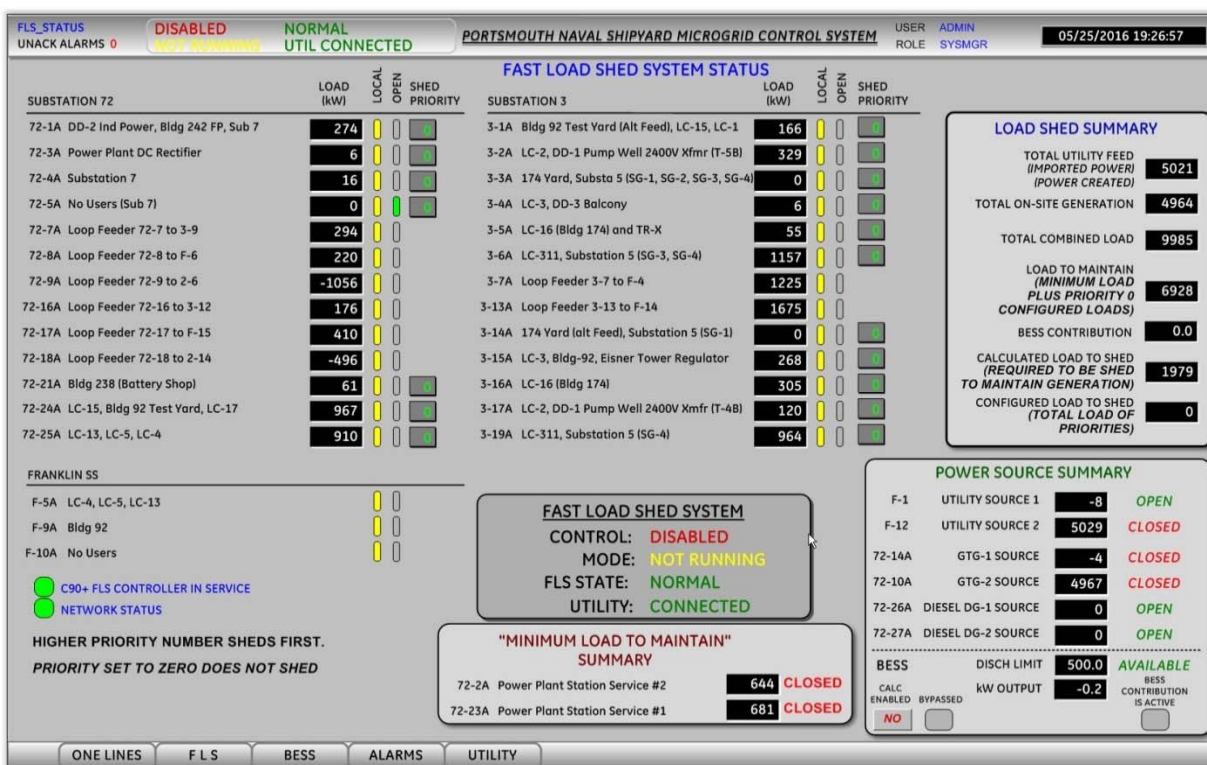


Figure 5-3. Main MCS/FLS HMI Screen

Data Storage and Backup: The F35 records data and the HMI/SCADA system automatically retrieves data and stores in a historian. The Dell PowerEdge R720xd server is equipped with a 1 TB HDD.

Non-standard Data: Operator Logs were completed after each event. Examples of these logs are contained in the Performance Verification Test document, which is included in Appendix B of the Final Report.

Phase II – BESS, Participation in the ISO-NE Regulation Market

The SEL-735 Power Quality and Revenue Meter was built to order for this demonstration by Schweitzer Engineering Laboratories and was shipped with certificate of calibration. This meter is accurate to at least 0.3%.

The D400 will be used to log Modbus communication points over Ethernet so calibration for this device is not applicable.

All other data collection and reporting is performed by ISO-NE and is transmitted to ISO-NE via the DNP3 protocol over a dedicated MPLS network.

These devices were ultimately not utilized for operation in the ISO-NE pilot program; however, the SEL-735 did prove to serve as a secondary meter to capture dispatch capacity of the BESS during Phase I.

5.6 DATA RESULTS

See the following appendices of the Final Report to view data results:

APPENDIX B – Performance Verification Test Plan

APPENDIX C – Performance Verification of the Fast Load Shed Solution

APPENDIX D – Event Logs for Live Event Testing of the Fast Load Shed Solution

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6.0 PERFORMANCE ASSESSMENT

See Appendix C in the Final Report for the complete reports.

Results for Quantitative Performance Objectives

Energy Security – The simulation tests and the live tests met the performance requirements by successfully islanding the Shipyard. The MCS FLS tripped sufficient load to keep the GTGs online and maintain a steady-state generation – load balance.

Proficiency of MCS to Maintain Generation – Load Balance for LoU – As expected, the FLS performed flawlessly once the settings were established for the Shipyard. The existence of the multiple loop feeders at PNS provided a high level of power reliability as more than one loop could trip without any loss of load. However, this configuration required unique settings and control for the C90^{Plus}. The detection of the LoU was done by monitoring the tripping of the utility tie breakers. This is the standard practice at existing installations of the C90^{Plus}.

Normally, the amount of utility power lost would be a key factor in determining which priority loads to shed. In this demonstration, the power level supplied by the utility was monitored by the MCS/FLS to provide a complete picture of the PNS system. However, the measurement of the power flows on the loop feeders tied to the Power Plant and Substation 3 became the key power measurement used to establish which priority loads would be tripped. Further, the MCS/FLS had to trip the loop feeders to isolate the power island. The ability of the MCS/FLS to accommodate this design demonstrated the flexibility of this technology. The potential for expansion of the MCS/FLS to include Substation 2 and Franklin in the FLS calculations will, in fact, simplify the operation of the scheme and reduce the tripping duty on the loop feeder breakers.

Demonstration of Fast Load Shedding – The MCS FLS performance surpassed the expected performance criteria. The existing F1 utility tie breaker did not have a spare ‘b’ contact available to indicate the LoU. The design added an auxiliary relay into the ‘b’ contact circuit. This auxiliary relay added a two-cycle delay in the detection of LoU. The FLS acted to issue shed commands in 3 ms, and the Shipyard was islanded and load shed within 32–40 ms of detecting the LoU. Overall trip time, including the two-cycle delay, was a maximum of 72 ms. See Appendix D of the Final Report for the waveforms from Live Test #1.

AAC of Lost Production – The calculation of the avoided cost requires (1) historical average of the number of outages, (2) average length of the outages, and (3) hourly value of lost production. The Shipyard experienced three live events over the demonstration period. Based on interviews of PWD staff and experience onsite since 2001, the length of outages was from 30 minutes to 2 hours. The restoration of the Shipyard following each live test was accomplished within one hour. This included time to collect records, verify all substation breakers were in local control, restore loads, and re-synchronize to the utility. See Section 7.0 for further calculations and results.

BESS Participation in Transition to Island Mode – The control of the BESS by the D400 was tested in a separate simulation test that duplicated a summer scenario where one GTG was online. The C90^{Plus} initiated the mode change to Microgrid operation and the D400 directed the BESS to ramp up at its maximum rate to discharge 500kW. The response time for this change was <0.5 seconds.

This included a 200-ms delay for the BESS Controller to change operation mode to Microgrid Dispatch, another 200 ms for the BESS Controller to execute the D400 commands, and 16 ms for the BESS to achieve maximum output. The approximate overall time to achieve maximum BESS discharge output was 416 ms.

Another portion of this performance objective was related to participating in the Avoided Cost of Lost Production. The plan was to capture and analyze value of the BESS saving additional loads above what could be carried by the Combustion Gas Turbines (CTGs) during an FLS event. This is the function previously noted as a “bridge” where the BESS would hold load until the emergency generators came online. Ultimately, getting the GE C90^{Plus} to properly include this capacity in its calculation was unsuccessful. Additional programming and tests would need to be performed to verify if this function is viable to count towards further savings in avoided production costs.

Results for Qualitative Performance Objectives

Ease of Use – The Power Plant Operators were provided hands-on training in their interface with the MCS/FLS. The HMI screens underwent a number of changes as the Shipyard gained experience. Overall, NAVFAC personnel appreciate the capabilities of the MCS/FLS and have instituted and adjusted the necessary operational controls and procedures. The changes in the HMI have come about as the Operators have become more familiar with the system and have requested the simplification and reduction in the number of steps required to enable/disable the system and to shorten these processes.

Operational Value of MCS/FLS – NAVFAC Power Operation management have become key supporters of this solution and they appreciate the fact that they do not have to experience a shutdown/trip of the GTGs following a LoU event. They have expressed satisfaction with the solution by moving ahead with the addition of a remote viewer at the Power Operations Building and have begun to discuss plans to expand the solution to cover Franklin Substation and Substation 2. NAVFAC personnel also recognize that the F35 controllers have the capability to provide protection functions that would replace the existing solid state relays.

Transferability of MCS-FLS application to other DoD sites – Ameresco is moving forward with applying the technology at other DoD facilities such as Parris Island and Soto Cano. GE is also actively involved with an ESPC project at Diego Garcia Naval Station. Furthermore, PNS has released an ESPC for development since award of this demonstration and selected Ameresco to perform. This new ESPC will build out the demonstration to include additional generation and will extend to the remaining two substations (Franklin Substation and Substation 2).

7.0 COST ASSESSMENT

The following costing and valuation analysis provides information useful to those who may be considering developing a project similar to this demonstration. Included are the upfront costs to purchase major technology components, design and build the system, and the routine maintenance and fees required to operate the system over its lifetime. Operational value of these systems comes in the form of avoided costs and generation of revenue through participation in ancillary services. Both technologies offer quantifiable value to a project.

7.1 COST MODEL

Table 7-1. Cost Model for MCS/FLS

Element	Data Tracked During the Demonstration	Costs
Hardware Capital Costs and Design, Programming, Training	Including: C90, F35s (x8), D400, Server, GPS Clock, Network Switches, Test Switches, UPS units, and Cabinets. See Section 2.1 Included in this purchase is the design and programming necessary to assure a fully operational system crafted specifically to the site, this is a service provided directly by the hardware vendor.	\$ 965,658
Engineering & Design	Installation Design focused on the mechanical, electrical, and civil engineering trades. The integration of the Microgrid Control System and Fast Loadshed System for this demonstration, as in many cases with other DoD facilities, includes retrofitting components into an existing electrical distribution system. Including in-depth review of existing electrical drawings and operating procedures.	\$ 172,913
Installation costs	Labor and materials required to install the system per the Installation Design drawings. This includes substantial wire pulls within the medium voltage electrical breaker lineups. It should be noted that there is potential in the future to utilize fiber optic conversation routers to be housed at each breaker housing and then fiber optic run back to the MCS/FLS control cabinets. This will greatly reduce the volume of copper wire needed and the labor to pull that wire.	\$ 180,985
Project Management & Overhead	We included in this estimate the cost for Project Management to coordinate the design, submittals, scheduling, installation, commissioning, and training for the system. Working with the government, one should expect the facility personnel to be very engaged through the process, requiring a high level of coordination and review through each step of the project from design to commissioning. Note: A demonstration project requires additional milestones and data collection/analysis which other projects may not require.	\$ 250,000
Maintenance	An annual service agreement is recommended to be purchased with the MCS/FLS vendor to provide phone support and two visits to site per year. Maintenance should include control cabinet inspections, dusting of equipment, UPS maintenance, and firmware/software updates.	\$ 28,000/yr
Hardware lifetime	Industrial based electronics and software packages should be expected to be supported by vendors past a number of generation updates of their technology. Though the hardware may be capable of lasting longer than 20yrs, there will be a point in time when the vendor will no longer provide support for components for earlier product lines.	20yrs
Total Upfront Cost	Not Including Annual Maintenance	\$ 1,569,556

* Pricing above is based on a system primarily designed to perform FLS on up to 30 medium voltage circuits, which is a representation of a system of a high complexity for a government facility. We would expect many facilities to require half or even a quarter of this many circuits. The estimator should keep in mind that utilizing the MCS for control of Distributed Generation Resources (DERs) was not part of this scope and carries a high cost to implement not included in this project.

Table 7-2. Cost Model for BESS

BESS Cost Element	Data Tracked During the Demonstration	Costs in 2013	Estimated Cost Today
Hardware Capital Costs and Training	Including: Batteries, Enclosure, Power Conversion System, and Controls. It must be noted that our cost estimates for if this system were built today are dramatically lower. This is due in part to manufacturer selection, as cost for systems vary across competitors. There has also been a downward trend in system costs across the Li-Ion battery market year over year in the range of 15%/yr.	\$ 1,043,910	\$ 365,252
Engineering, Design, Permitting	Installation Design focused on the mechanical, electrical, and civil engineering trades. The integration of a BESS for this demonstration, and as in many cases with other DoD facilities, includes retrofitting components into an existing electrical distribution system.	\$ 167,571	
Installation costs	Labor and material required to install the system per the Installation Design drawings. This includes any demolition necessary, forming of pads, conduit runs, and cable. It must be noted that for this specific project, we had access to an existing breaker which would otherwise need to be accounted for. Also, we were able to utilize sub-contractors who were already on-site which substantially reduced electrical and	\$ 78,905	
Project Management & Overhead	We included in this estimate the cost for Project Management to coordinate the design, submittals, scheduling, installation, commissioning, and training for the system. When working with the government, one should expect the facility personnel to be very engaged through the process, requiring a high level of coordination and review through each step of the project from design through commissioning. Note: A demonstration project requires additional milestones and data	\$ 150,000	
Battery Regen @ Yr 11	Li-Ion battery technology has a long life expectancy in the 20yr range, however this is heavily dependent on the number of charge/discharge cycles performed over the life of the system. For providing Frequency Regulation, as this project was intended for, we expect that life span to drop to around 10yrs for the cell chemistry. Since the rest of the BESS components still have a 20yr life it is economically wise to invest money in replacing the battery cells. As can be seen in the graphs in Section 7.3, the economic life and value of the investment is dramatically increased in performing this added Regen cost. Cost for Regen was	\$ 417,564	\$ 146,101
Facility Operational Costs	Fee to ISO-NE to provide MPLS connection in order to participate in Reg Market	\$ 400/mo	
Maintenance	BESS components require very little annual maintenance, the costs in this line item are associated mostly with annual inspection.	\$ 5,000/yr	
Hardware lifetime	Assuming Battery Regen is performed.	20 Years	
Total Upfront Cost	Not Including Annual Maintenance or Regen	\$ 1,440,386	

* Pricing above is for a 500kW/500kWh system. In terms of scalability, our market experience is that the cost to capacity curve is linear up to multi MW/MWh systems. This pricing does not apply to utility scale projects in the 10s of MW scale.

7.2 COST DRIVERS

Battery technology costs are on a downward trend with the market seeing on average a 15% reduction year over year. Over the demonstration period of this project, this trend was confirmed. The analysis covered in Section 7.3 goes into detail on the findings. The outcome is that projects that may have not been feasible only three years ago may now be viable due to the reduced cost in both Li-ion chemistry and PCSs. When looking at revenue opportunities, the availability of an ancillary services market for a system to participate in should also be considered. As of today, there are a number of markets in development or already operating, with the most mature being PJM, ISO-NE, and CAISO. Other regions in development that should be considered are NY-ISO, ERCOT, and MISO. See Figure 3-1 in Section 3.0.

7.3 COST ANALYSIS AND COMPARISON

The following steps in performing the life-cycle cost (LCC) analysis were taken from the Life-Cycle Costing Manual for the Federal Energy Management Program, NIST Handbook 135, 1995 Edition (NIST Handbook 135).⁴

PART I: TABLES FOR FEDERAL LCC ANALYSIS

Single Present Value (SPV) and Uniform Present Value (UPV) Factors for Non-Fuel Costs

Table 7-3 presents the SPV factors for finding the present value of future non-fuel, non-annually recurring costs, such as repair and replacement costs and salvage values. The formula for finding the present value (P) of a future cost occurring in year t (C_t) is the following:

$$P = C_t \times \frac{1}{(1 + d)^t} = C_t \times SPV_t,$$

where d = discount rate, and

t = number of time periods (years) between the present time and the time the cost is incurred.

Table 7-4 presents UPV factors for finding the present value of future non-fuel costs recurring annually, such as routine maintenance costs. The formula for finding the present value (P) of an annually recurring uniform cost (A) is the following:

$$P = A \times \frac{(1 + d)^N - 1}{d(1 + d)^N} = A \times UPV_N,$$

where d = discount rate, and

N = number of time periods (years) over which A recurs.

UPV (FEMP): To compute the present value of an annually recurring maintenance cost for a renewable energy system over 20 years, go to Table A-2 [NIST Handbook 135], find the 3.0 % UPV factor for 20 years (14.88), and multiply the factor by the annual maintenance cost as of the base date.

⁴ <https://www.nist.gov/publications/life-cycle-costing-manual-federal-energy-management-program-nist-handbook-135-1995>.

Table 7-3. Annual Supplement to NIST Handbook 135 (2013) Table A-1 Showing SPV Factors for Finding the Present Value of Future Single Costs (Non-Fuel)⁵

Table A-1. SPV factors for finding the present value of future single costs (non-fuel)

Number of years from base date	Single Present Value (SPV) Factors		
	DOE	OMB Discount Rates ^a	
	Discount rate 3.0 %	Short term ^b -0.4 %	Long Term ^c 1.1 %
0.25	0.993	1.001	0.997
0.50	0.985	1.002	0.995
0.75	0.978	1.003	0.992
1	0.971	1.004	0.989
2	0.943	1.008	0.978
3	0.915	1.012	0.968
4	0.888	1.016	0.957
5	0.863	1.020	0.947
6	0.837	1.024	0.936
7	0.813	1.028	0.926
8	0.789	1.033	0.916
9	0.766	1.037	0.906
10	0.744	1.041	0.896
11	0.722		0.887
12	0.701		0.877
13	0.681		0.867
14	0.661		0.858
15	0.642		0.849
16	0.623		0.839
17	0.605		0.830
18	0.587		0.821
19	0.570		0.812
20	0.554		0.803
21	0.538		0.795
22	0.522		0.786
23	0.507		0.778
24	0.492		0.769
25	0.478		0.761
26	0.464		0.752
27	0.450		0.744
28	0.437		0.736
29	0.424		0.728
30	0.412		0.720

^aOMB discount rates as of April 2013.

^bShort-term discount rate based on OMB discount rate for 7-year study period.

^cLong-term discount rate based on OMB discount rate for 30-year study period.

⁵ <http://dx.doi.org/10.6028/NIST.IR.85-3273-28>.

Table 7-4. Annual Supplement to NIST Handbook 135 (2013) Table A-2 Showing UPV Factors for Finding the Present Value of Annually Recurring Uniform Costs (Non-Fuel)⁶

Table A-2. UPV factors for finding the present value of annually recurring uniform costs (non-fuel)

Number of years from base date	Uniform Present Value (UPV) Factors		
	DOE	OMB Discount Rates ^a	
	Discount rate 3.0 %	Short term ^b -0.4 %	Long Term ^c 1.1 %
1	0.97	1.00	0.99
2	1.91	2.01	1.97
3	2.83	3.02	2.94
4	3.72	4.04	3.89
5	4.58	5.06	4.84
6	5.42	6.08	5.78
7	6.23	7.11	6.70
8	7.02	8.15	7.62
9	7.79	9.18	8.52
10	8.53	10.22	9.42
11	9.25		10.31
12	9.95		11.18
13	10.63		12.05
14	11.30		12.91
15	11.94		13.76
16	12.56		14.60
17	13.17		15.43
18	13.75		16.25
19	14.32		17.06
20	14.88		17.87
21	15.42		18.66
22	15.94		19.45
23	16.44		20.22
24	16.94		20.99
25	17.41		21.75
26	17.88		22.51
27	18.33		23.25
28	18.76		23.99
29	19.19		24.71
30	19.60		25.43

^aOMB discount rates as of April 2013.

^bShort-term discount rate based on OMB discount rate for 7-year study period.

^cLong-term discount rate based on OMB discount rate for 30-year study period.

⁶ <http://dx.doi.org/10.6028/NIST.IR.85-3273-28>.

The following calculations represent Present value (P) using the methods previously described in the NIST 135 Handbook. The “Calculated” values were performed in Microsoft Excel using the two equations as seen below. The “From Table” values are used for proofing the equations and utilize Tables A-1 and A-2 taken from the NIST 135 Handbook Annual Supplement (see Tables 7-3 and 7-4). By bringing all the associated costs and revenue to Present value, a comparison is made to the initial costs of the system. Figure 7-1 and Figure 7-2 graphically demonstrate the calculations and show the breakeven point on the upfront investment.

$$P = A \times \frac{(1+d)^N - 1}{d(1+d)^N} = A \times UPV_N,$$

$$P = C_t \times \frac{1}{(1+d)^t} = C_t \times SPV_t,$$

Values at time of Demonstration (2013)

P_Initial Cost	\$ (1,440,386)	
	Calculated	From Table
P_maint	\$ (74,387)	\$ (74,400)
P_revenue	\$1,487,747	\$1,488,000
P_regen	\$ (216,726)	\$ (223,200)
P_sum	<hr/> <hr/> \$1,196,634	
P_variance	\$ (243,752)	

Total costs versus revenue over the 20-year life of the system resulted in a variance of \$(243,752) in the negative and a breakeven point out past year 20, indicating that this project was not economically feasible at the time of initial investment. However, since the award of this demonstration (2013), costs of battery system components have come down dramatically. Though due to a number of factors, the two primary drivers have been related to an increase in competition with a wider choice of manufacturers entering the market and an increase in economies of scale in manufacturing.

There are multiple sources of information that project on average a 15% cost reduction year over year for battery systems. The findings support this projection. The following calculations represent Present value (P_n) for a system procured in 2017, with the same maintenance and market revenue assumed.

Values at Present (2017)

P _n Initial Cost	\$(761,728)	
	Calculated	From Table
P _{maint}	\$(74,387)	\$(74,400)
P _{revenue}	\$1,487,747	\$1,488,000
P _n regen	\$(109,158)	\$(112,419)
P _n sum	<u>\$1,304,158</u>	
P _n variance	\$542,474	

Total costs versus revenue over the 20-year life of this system resulted in a variance of \$542,474 in the positive and a breakeven point at the end of year 9, indicating that this project is in fact economically feasible in present conditions.

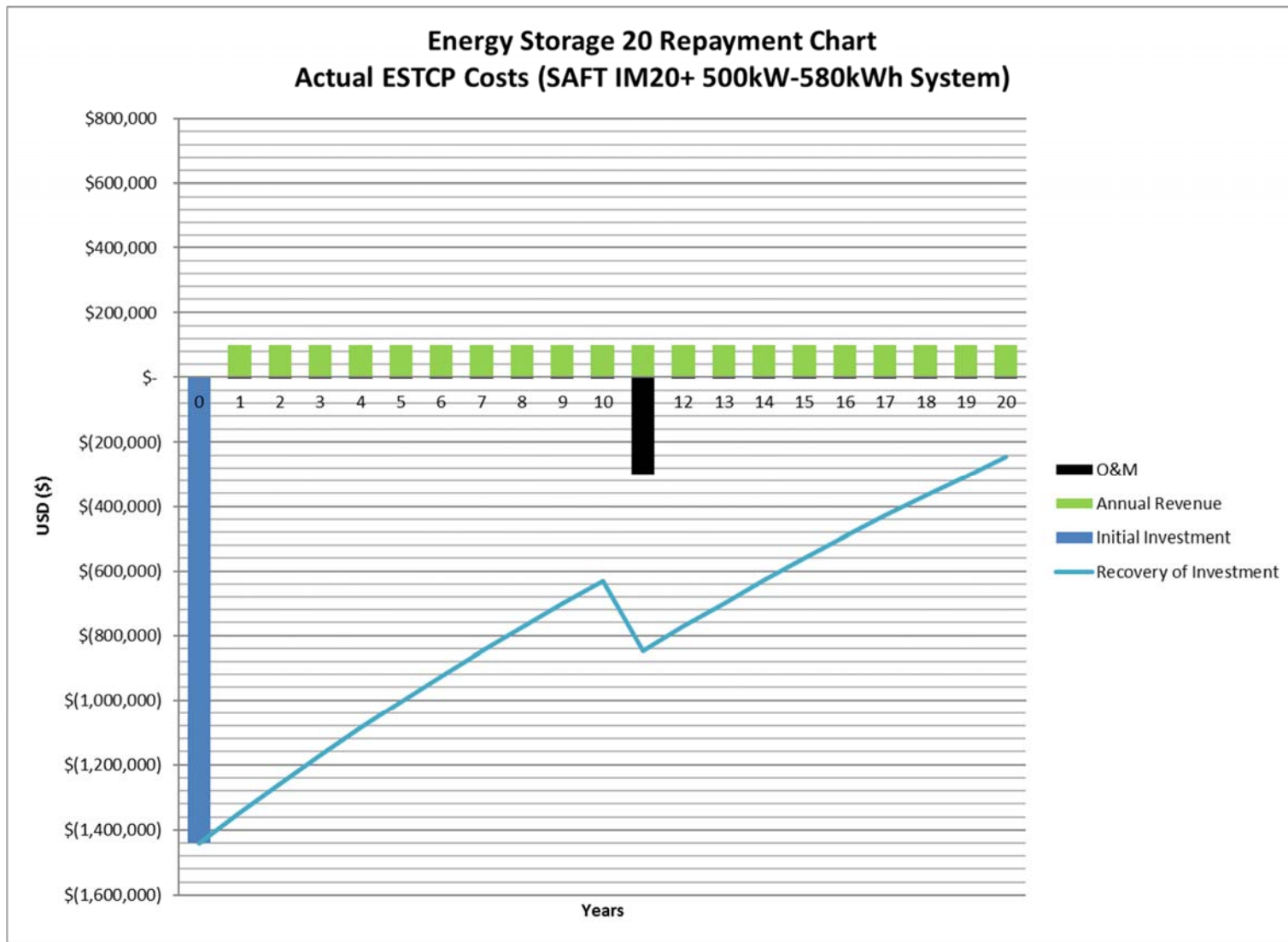


Figure 7-1. 20-Year Economics of the 500 kW/580 kWh Saft IM20+ BESS Participating in ISO-NE Regulation

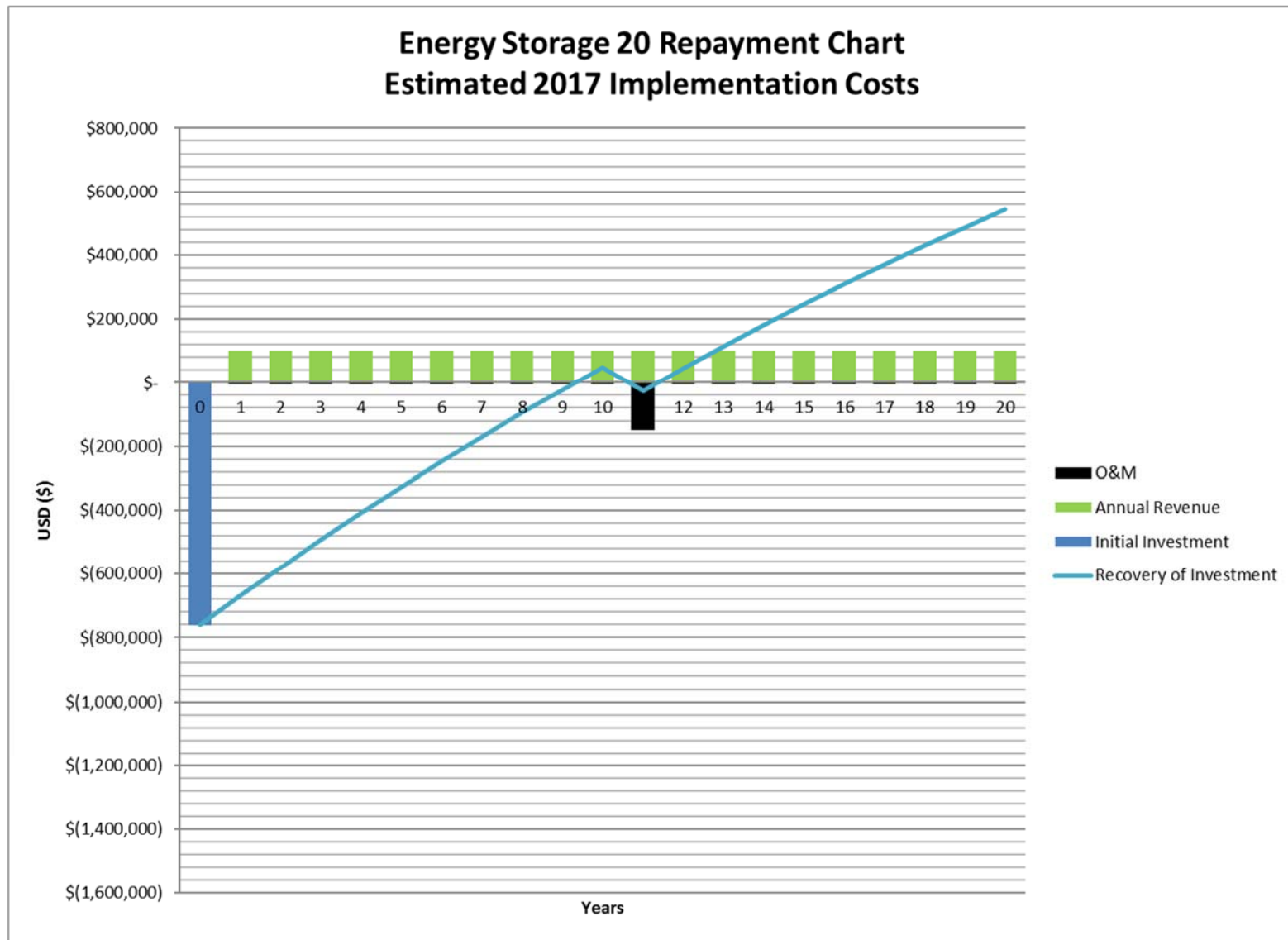


Figure 7-2. Expected 20-Year Economics of a 500 kW/500 kWh BESS with 2017 Equipment Pricing Participating in ISO-NE Regulation

Calculating Market Revenue (P_revenue)

Ameresco estimated annual revenue that can be received as payment for participation in the ISO-NE regulation ancillary services market. To determine this estimated revenue, Ameresco conducted its own research into the ISO-NE market including analysis of multiple years of actual historical clearing price data and utilized a third-party consulting service to conduct analysis of the market. It should be noted that this market is a merchant market and as such the actual revenue garnered is variable from year to year, so there is a certain level of uncertainty with respect to Ameresco's revenue estimates since this is a newly emerging market.

Research determined that Ameresco assumed an average hourly Regulation Capacity Clearing Price of \$25.00 per megawatt hour. Ameresco assumed an annual hourly participation of 8,000 hours. It is noted that the newly established minimum capacity for participation eligibility is 1,000 kW; however, for the sake of example for this project an assumed participation capacity of 500 kW is used to calculate the annual revenue estimate as:

Annual Regulation Revenue

$$\begin{aligned} &= \text{Average Hourly Reg Payment} * \text{Annual Hours of Service} \\ &* \text{Capacity Provided} = \left(\frac{\$25.00}{MWh} \right) * \left(8000 \frac{\text{hours}}{\text{year}} \right) * (0.5MW) = \frac{\$100,000}{\text{year}} \end{aligned}$$

AAC of Lost Production

During this demonstration, the value in the avoided down-time realized in maintaining priority loads during an LoU through implementation of the FLS system was taken into consideration. Through interviews with PWD staff and experience onsite at PNS since 2001, the facility on average experiences an LoU two to three times per year. Over the demonstration period, three LoU events occurred, confirming this average. Pre-existing to the implementation of FLS, the facility would experience a base-wide blackout during an LoU. This was due to an imbalance between a greater number of loads versus available onsite generation capacity. The overload resulted in the GTGs tripping off-line. Blackouts ranged from 30 minutes up to 2 hours until the GTGs were re-started and power to priority loads was restored. With the FLS activated, this blackout period can be eliminated by matching the number of priority loads to be saved to the available onsite generation capacity.

Though the Navy does not budget for down-time in production, PWD staff indicated that a good estimate is a cost of \$100,000/hour (hr). Assuming an event lasts on average one hour with the total facility load on average being 15 MW, an average cost per MW (\$/MW) for the value of generation in relation to production cost can be estimated.

$$\text{Production Cost per MW} = \frac{\left(\frac{\$100,000}{1hr} \right)}{15MW_{load}} = \$6,666/MW$$

The FLS is capable of saving between 5 MW and 10 MW of priority loads depending on the number of GTGs operating at time of LoU. Two typical modes of operation exist: summer with one GTG (5 MW) online, and winter with two GTGs (10 MW) online. Assuming each generator is running at full capacity, which is typical operation, two additional calculations were performed to come to a total Lost Opportunity Cost (LOC) per event at the time of an LoU.

$$LOC_{Summer} = \$6,666 \times 5 \text{ MW} = \$33,000 \quad LOC_{Winter} = \$6,666 \times 10 \text{ MW} = \$66,000$$

Note that one of the performance objectives was to capture and analyze value of the BESS saving additional loads above what could be carried by the CGTs. This is the function previously noted as a “bridge” where the BESS would hold load until the emergency generators came online. Ultimately, getting the GE C90^{Plus} to properly include this capacity in its calculation was unsuccessful. Additional programming and tests would need to be performed to verify if this function is viable to count towards the LOC.

During the demonstration, two LOC_{Summer} events and one LOC_{Winter} event were captured, which resulted in an AAC of \$132,000. Dividing the combined implementation costs found in Table 7-1 by the ACC, a simple payback on the investment can be estimated.

$$Simple \ Payback = \frac{\$1,569,556}{(\$33,000 \times 2) + (\$66,000 \times 1)} = 11.89 \text{ Years}$$

The result is a 12-year payback on the system, which in theory this is an attractive savings. However, it must be realized that an LOC is not a value that most Government facilities take into consideration when budgeting for operations. As an energy services company (ESCO) providing ESPCs to the Federal Government, it is Ameresco’s experience that costs of this nature are not presently identified under the list of approved energy conservation measures (ECMs).

In review of the positive outcome from the above results, there is a possibility of further discussions regarding the future potential of the Government opening up LOC as a potential ECM to be added to an ESPC. The potential to apply such cost savings to other facilities is very real and has a broad application. Almost any facility that serves a daily operational duty could benefit from deferring a disruption in its function during an emergency power outage, and having the opportunity to include this in an ESPC could provide means to fund implementation of the technology.

Furthermore, the implementation of technologies of this nature provide a greater yet intangible value above LOC in the form of increasing national security, which can ultimately avoid casualties in the form of both Government property and lives during times of crisis.

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8.0 IMPLEMENTATION ISSUES

Battery Manufacturers: One challenge in bringing the demonstration from concept to activation was procurement of the grid-tied battery. Over the development phase, battery companies—some of whom provided pricing proposals for this project—underwent substantial changes, from bankruptcy and plant closures, to limited component availability and redesign of systems resulting in extended product lead-times.

Battery Location and Installation: Another particular challenge faced during the demonstration was determining a final location for the BESS. Choosing a place for the battery proved to be troublesome due to the weight, dimensions, and mounting requirements of the integrated shipping container.

BESS Communications Integration

Saft IM20 and Dynapower BESS Site Controller: There were a number of programming challenges during integration of the communication devices between the Saft IM20, Dynapower Site Controller, GE D400, and ISO-NE control center. This demonstration was the first time these components had been programmed to communicate with each other, and dealt with a number of communication protocols including Modbus, CANbus, and DNP3.

BESS Site Controller and ISO-NE Network: During ISO-NE circuit testing, it was identified that the Site Controller was not reporting Reg High/Low Limits as expected. Dynapower and SGC Engineering worked with Ameresco to better understand the ISO-NE communication register, which operates on DNP3, which is converted into Modbus via an RTU housed within the Site Controller cabinet.

BESS Site Controller and GE MCS/FLS: Challenges were experienced during integration of the BESS Site Controller communications into the GE MCS/FLS system, rooted in the fact that this was the first time GE had worked to integrate with these two specific manufacturers and the first time the GE team integrated a BESS into an FLS schema. The result was that during PVT in December 2015, the BESS was only partially operational. Testing proved that the unit could operate as a “buffer,” however additional programming in the C90^{Plus} controller was necessary in order to operate as a “bridge.”

BESS Reliability/Quality Control

See Appendix K in the Final Report for a complete list of Saft IM20 Warranty Issues to date.

Battery Fire Suppression System Certification: The Navy required additional inspection and acceptance of the battery fire suppression system than what was provided with the Saft container and what had been accounted for.

Regulation Market Rules: ISO-NE set up a pilot program that ran until March 31, 2015, that aligned well with the planned demonstration period. At expiration of the pilot, participants were required to comply with the new rules, under FERC Order 755, or discontinue service. The largest challenge in ISO-NE’s new program was meeting a 1 MW minimum participation capacity (the project is 500 kW).

Interconnection Agreement: Unfortunately, an IA was not obtained in time as required by ISO-NE in order to participate in the pilot program. This process was extremely slow and ultimately resulted in the passing of the expiration of the pilot program on March 31, 2015, with a contract finally being signed and executed in May 2015.

MCS/FLS Testing and Operation: During PVT in December 2015, a number of errors in settings and programming were uncovered within the GE hardware, namely the F35s, C90, and D400. Even though the majority of commissioning had already been performed, there were certain operations of the system that could not be tested until the PVT, simply because some functions required activation and triggering of the FLS. Due to the extreme sensitivity of PNS maintaining power, there was a small window of approval to perform the PVT. GE was able to successfully complete the PVT, and ultimately gained approval to activate the system to commence with the 12-month demonstration period.

Islanding and Power Plant Stability: Over the course of the 12-month demonstration period, PNS experienced three accounts in LoU. In each case, a full LoU and successful activation of the FLS occurred; however, two of these events resulted in the GTG tripping off-line and a full blackout of the Shipyard. See the Final Report for full documentation of each event.

APPENDIX A POINTS OF CONTACT

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